MANUFACTURING LEAD TIME ESTIMATES FOR MAKE TO ORDER MANUFACTURING SYSTEMS

A Thesis Submitted
in Partial Fulfillment of the Requirements
for the Degree of

Master of Technology

by

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to the

DEPARTMENT OF INDUSTRIAL AND MANAGEMENT ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY, KANPUR

APRIL, 1997

CERTIFICATE

It is to certify that the work contained in the thesis entitled "**MANUFACTURING LEAD TIME ESTIMATES FOR MAKE TO ORDER MANUFACTURING SYSTEMS**" by Rajeev Kumar Sharma (Roll No. 9511411), has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

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ABSTRACT

Lead time estimation of the jobs in quite advance, in a make to order environment is taken as the problem for this study. We choose a forecasting based method for the calculation of the lead times of the jobs. In this study we have recognised some factors on which the lead time of a job depends. Regression analysis is used to develop models for the lead time estimation. For developing a model by using these factors we will need the actual lead time of the parts .In the present work a simulation model, using the event oriented simulation approach is developed for calculating the lead time of the jobs. Programming language 'C' is used for implementation due to the flexibility in modelling system conditions and due to its efficiency in handling memory and the computational speed. Linked allocation approach is used for storing lists of records. The motivation behind the use of linked allocation approach was the reduction in the time required to process certain kinds of lists and the reduction in the computer memory required for storage. In our simulation model we incorporated some of the features of actual shop environment such as machine break downs, labour absenteeism, arrival of immediate priority part. We used twelve different job dispatching rules in our simulation model for sequencing the jobs on the machines.

ACKNOWLEDGEMENT

I take this opportunity to express my gratitude towards Prof. A. K. Mittal for his invaluable guidance, constant encouragement and an uncompromising attitude regarding the academic standards inspired and motivated me to work ever harder. I also feel indebted to Prof. Kripa Shanker, Prof. A. P. Sinha, Prof. T. P. Bagchi, Dr. R. R. K. Sharma and Dr. Rahul Varman of IME department who imparted unto us fabulous information and skills.

For my thesis, I owe much to my colleague and friend Mahesh Gupta with whom I shared my long stay at IIT Kanpur and HAL Lucknow while we worked jointly on our thesis. Atul Dobhal deserves special mention for the help he extended in programming.

This thesis could not have materialised without the help of Mr. A. C. Trivedi who went out of his way to let me print it in unseemly night hours.

RAJEEV KUMAR SHARMA

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INTRODUCTION AND LITERATURE REVIEW[1]

1.1 Overview

The increasing surge in the competitive arena has brought the attention to 'manufacturing effectiveness' as a potent tool for success, which was for quite long overshadowed by finance and marketing, advanced and nurtured by the industrialised west. In a competitive world where supply-demand balance is more skewed towards the former, the customer is expected to receive enough choice. The companies have realised that marketing alone can not sell the product. Increasing the variety of products, model proliferation, cannibalisation of one product by another has introduced a new challenge to manufacturing. The need to achieve co-ordination with the customer's value-chain through strict adherence to the due date commitment has made the scheduling problems particularly of the job shop increasingly complex in face of complexity and varied product portfolio.

A process strategy in production system is the approach that an organisation takes to transform resources into goods and services. The main concern of the organisations have been to achieve high quality, lower costs, higher capacity utilisation, reduction in time taken to manufacture a product, better inventory management etc.

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[1] Some portions of this chapter are common with the M.Tech. thesis entitled, " Due date assignment and information system design for shop control in job shop environment " , April 1997 , by Gupta, M. , Department of Industrial and Management Engineering , IIT Kanpur(due to both work being the parts of a joint project

1.2 Classification of Production System

Great diversity in manufacturing system makes it desirable to analyse it by classification. A classification on the basis of volume and variety, divides production system into two different environment. One which manufacture low variety and high volume of product, generally called flow shop. such type of manufacturing systems come under continuous process and have very long runs. While the other type of manufacturing systems deal with high variety and low volume. These are called job shop type of production system. Processing of components in job shop is intermittent in nature. Flow shop utilises the benefit of having low variety and high volume because movement of parts differ marginally and hence can utilise the benefit of classic assembly line. On the other hand in job shop different parts follow different routes. Since volume is less one can not go for special purpose equipment, automated movement of parts etc. like in flow shop. To reduce cost and increase utilisation one have to find out solution with existing facility. The job shop type of production system would ,thus ,involve setting up of different groups of machinery, each specially in certain kinds of operations on the jobs. This would ensure the flexibility of the system and its capacity to produce a variety of products.

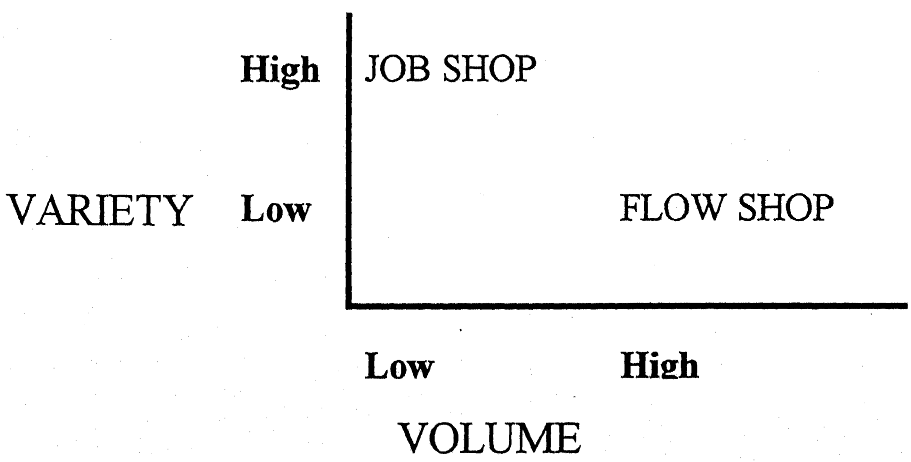

Figure 1.1 : Classification of production system by volume and variety.

However the number of products of each kind would have to be small enough to render a specialised production line as uneconomic for that particular find of product. Thus for the large types of products to be manufactured, this short of production system would be more economic and suitable then individually customise flow line. However, the problem of optimal utilisation of this type of production system would remain unresolved unless one could ensure proper co-ordination and allocation of jobs to individual machine on a continuing basis.

Manufacturing companies can also be distinguished by those that manufacture each customer order on a unique basis(make to order), those that assemble a wide variety of finished goods from a smaller set of standardised options(assemble to order), and those that produce goods for inventory(make to stock).

1.2.1 Make to Order

The make to order company , in general, carries no finished-goods inventory and builds each customer order as needed. This form of production is often necessary when there is a very large number of possible product configurations, and, thus, a small probability of anticipating the exact needs of a customer. In this business environment, customers expect to wait for a large portion of the entire design and manufacturing lead time.

1.2.2 Assemble to Order

The assemble to order firm is typified by an almost limitless number of possible end-item configurations, all of which are made from combinations of basic components and subassemblies. Customer delivery times are often shorter than total lead times, so

production must be started in anticipation of customer orders. The large number of end-item possibilities make forecasting of exact end-item definitions extremely difficult, and stocking of end item very risky. As a result , the assemble to order firm attempts to maintain flexibility, starting basic components and subassemblies into production, but, in general, not starting final assembly until a customer order is received.

1.2.3 Make To Stock

The make to stock company produces in batches, carrying finished goods inventories for most, if not all, of its end items. Firms that make to stock are often producing consumer products as opposed to industrial goods, but many industrial goods, such as supply items, are also made to stock.

1.3 Characteristics of Job Shop Type Production System

As stated earlier, the job shop type production system involves setting up of different type of operations, the flexibility of the machine within the types of operations is generally ensured. The product required is then exploded into various components and sub-assemblies and each of these components is then allocated to different machines as per the requirement of sequence of operation and the availability of the individual machines. The problems in this job shop kind of production system relate mainly to the following :

- Special arrangement of machinery groups.
- Problems relating to material flow and handling for one machine to another.
- In process inventory reduction and reduction of each individual item.

- Optimum capacity utilisation for each machine.
- Meeting required due date of job and lead time estimation.
- Estimation of ordering point for bought out sub-assemblies and components in the products.
- Flexibility of system to deliver certain product ahead of schedule on urgent requirement.
- Requisite information and control system in view of the large number of components and sub-assemblies involved.
- Master production schedule(MPS) for all of the components and machines involved.

1.4 Discussion on Criteria For Efficient Production System

The last problem, however is a very difficult to solve mathematically in view of the diverse requirement and the production system involve. Optimal utilisation of installed machinery is generally critical for a firm to produce a low cost and competitive product. This could thus be taken as a criteria to optimally schedule the jobs, however, different delivery date requirements may cause any scheduling (done on the basis of optimum machine utilisation) to become redundant. Scheduling done exclusively with respect to delivery dates may result in sub optimal utilisation of machines. Also the throughput time of certain products may become very large, resulting in large in-process inventory. Thus reducing the make span of each individual product could also be a criteria for scheduling of jobs in such environment. It is amply clear that optimal scheduling of jobs under all these criteria is not an easy task. Some degree of prioritising is required based on the criteria which is of critical importance in a given situation. Elaborating on this point of critical

importance, in a unit manufacturing aircraft instruments for defence and civil requirements, meeting the due date for delivery of such instruments may be of critical importance. In a consumer durable products unit. since only gross demand estimates are known, machine utilisation and/or make span may be of critical importance. Thus one can identify some measures for establishing the efficient performance of a job shop type of production system.

1.5 Manufacturing Scheduling

A manufacturing system should be properly designed and controlled so as to achieve a high productivity and other objectives. While making various decisions, several aspects such as the availability of resources, utilisation of resources, setting due date of jobs, costs of implementing the decisions etc. need to be taken into consideration. An important aspect of the decision is industrial control which involves deciding upon the precise use of manufacturing facilities at each instant of time. Such type of decision making is commonly known as 'scheduling'. Even if the design of a manufacturing system has been done meticulously, scheduling assumes great importance for the smooth functioning of the system. Industrial scheduling problem differs greatly from one organisation to another. Sometimes the manufacturing process consists of a series of operations at one single work station or on only one physical part while at some other times operations require different equipment and skills on each of the many thousands of components. Sometimes inventories of finished goods are maintained to satisfy customer demands and at other times maintaining inventories becomes practically impossible under all conceivable circumstances. Because of such diversity and complexity it is better to analyse industrial scheduling problem according to the classification of the manufacturing environment. As

discussed in chapter 1, characteristics related to volume and variety of jobs play a key role in classification for the purpose of industrial scheduling and control. The two major types are : flow shop and job shop. A flow shop consists of facilities through which work flows in a serial fashion. Make-to-stock kind of products are manufactured in such environment. Being almost a deterministic system, where arrival and processing times are known in advance for all current and future jobs, it is possible to determine precisely (for a given set of rules of priorities and scheduling), when a job will be completed. While in job shop manufacturing system, where the jobs follow different processing pattern through the facilities it is difficult to predict these features. In the next section, the issues related to scheduling in job shops are elaborated.

1.6 Job Shop Scheduling

The scheduling problem, like any other decision problem, has three basic components : objective or measure of performance, constraints, and decision variables. Objective of scheduling can be job related (flow time, lateness, number of tardy jobs), machine related (utilisation) or related to both.

Job shop planning starts at the aggregate level. All the different kinds of jobs that might be done in some period of time are lumped together to determine work force and equipment requirements. The next phase of the scheduling problem is shop-loading which is the assignment of different kinds of work to various department and machines centers. This scheduling activity is unique to job shop. Tasks are ultimately assigned in specific order to persons and machines. This process is called sequencing.

Much of the literature on job-shop scheduling is concerned with sequencing rules, namely with the order in which jobs should be arranged for processing on individual machines, primarily with the object of minimising the mean job throughput time or job lead time (some times called the job 'flow time', being the time elapsed from the job arrival to its departure from the shop) or its standard deviation (or some weighted sum of the both). The due date (which is the prespecified date for completion of the job, sometimes called the 'delivery date') is often ignored together (Baker and dzielinski 1960, Conway *et al.* 1967) or is thought to be a constraint (imposed by the sales department or the customer) outside the control of the scheduler (Ashour and Vaswani 1972, Holloway and Nelson 1974). In the latter case , criteria other than the throughput time need to be considered , such as the distribution of missed due dates or costs associated with the earliness and lateness , and the effect of applying alternative rules on such criteria needs to be ascertained. A loading rule may then be prescribed so as to attain desirable levels of performance of the shop with respect to the missed due date.

Clearly such performance can be improved if, instead of confining the scheduler to a given array of due dates, the due date is so specified as to take account of the individual job expected processing time and of the level of congestion in the shop. In practice , of course , the scheduler is not free to assign due dates on his own, and the wishes of the customer in this respect undoubtedly play a significant role. Nevertheless , a method that prescribes desirable due dates can provide useful guidance when negotiating with customers.

In this context, a procedure for specifying due dates aims at forecasting the completion date of a given job under given operating conditions. In a purely deterministic system , where arrival and processing times are known in advance, not only for jobs in question, but

for all current and future jobs as well, it is possible by simulation to determine precisely (for a given set of rules of priorities and scheduling) when the job will be completed.

Much of the published work on the production planning and control tends to emphasis the development of planning procedures. However, of equal importance for successful production planning is the quality of the planning data , such as engineering data (routing sheets and bills of materials), capacity data (on the work force and work centers), and lead time data (suppliers lead time and manufacturing lead times). In intermittent production systems, commonly known as job-shops, the main problem of concern with the basic planning data are the uncertainties and variations in the manufacturing lead times .

The lead time of a part is composed of processing times and other delays. As far as the processing time (including set-up time) is concerned, it can be computed from the process sheet. But this is not the only contributor to total completion time of a job. There are many other events which consume time in uncertain manner, such as waiting time, transportation time etc. For example, at a point of time when a part is ready for processing but the machine on which it has to be loaded is busy in processing of some other job; so part will have to wait until processing of the loaded job is over. On its way of processing in the shop, when, how long and where a part will wait is, in general, difficult to predict in advance. Several factors such as machine break down, labour absenteeism , arrival of an immediate priority item etc. influence and contribute to such uncertainties. Uncertainties are also caused due to transportation time but these can be, to some extent, controlled with an efficient planning and control.

As mentioned before, the information about the time taken by a part in the shop, that is its processing time, waiting time, transportation time and inspection time collectively

constituting the lead time, is essential for planning and control and specially for scheduling of jobs to calculate due date, the most important criteria of job shop. Due date, sometimes also called 'delivery date', is the date for completion of the job.

Due date is decided using the estimation of lead time. Due date assignment is an important element in production control, affecting both timely delivery and the level of finished goods inventory, because product or service delivery systems are not necessarily capable of successfully achieving any arbitrary set of due dates.

1.7 Literature Review

Various procedures for assigning due dates to jobs arriving at a job shop have been described in the literature. Some of these studies are dealt with an environment where the arriving jobs had pre assigned due date and the objective is to device priority rules to attain acceptable due date performance. Other studies have considered a job shop where the due date of arriving jobs are set internally and jobs had to be scheduled to meet the assigned due dates. Objective of scheduling are often multidimensional, however factor of primary interest in job shop is 'due date Performance'.

Early research in the area of due date assignment focused on the comparison of heuristics which utilised information on the individual job attributes versus due date methods which ignored job characteristics. Some of the due date assignment rule investigations were conducted by Baker [1965] and Conway et al. [1967]. Four due date assignment rules were analysed in their research. The number of operation due date rule (NOP) assignees flow time proportional to the number of operations required for the job, constant allowance due date rule (CON) assignees a fixed flow allowance to all jobs, total work due

date rule (TWK) as a proportion of the job's expected total processing time and random allowance due date rule (RDM) randomly assignees flowtime within a designated range. Conway's research revealed that due date rules which incorporated job characteristics performed better then rules which ignored job characteristics.

Eilon and Chowdhury [1976] examined several procedures for specifying due dates, largely dependent on the expected processing time for job and on the level of congestion in the shop. The effect of these procedures is examined in the case of three loading rules (FIFO, SI and SI*) on waiting times, on missing due dates and on notional cost functions.

Malstorm and Moodie [1976] developed an algorithm to forecast a potential job costs and throughput times in a job shop. The algorithm utilises historically repetitive relationship between cumulative job costs and time. The job algorithm was developed and evaluated using actual historical data from a large job shop production facility.

Weeks [1979] focused on duel constrained job shops representing the systems which have limited labour and machine resources. He described a simulation study of assigning attainable or predictable due dates in hypothetical labour and machine constrained job shop setting of varying size and structure. Results of his study indicate that due date assigned based on expected job flow time and shop congestion information may provide more attainable due dates than rules based solely upon job characteristics. Better due date than performance appears to be achieved when due date oriented dispatching rules are employed and when the shop system is not structurally complex.

Seidmann and Smith [1981] formulated an objective function to minimise the expected aggregate cost per job subject to restrictive assumption on the priority discipline and the

penalty function. This aggregate cost includes (1) a cost that increases with increase in lead times, (2) a cost for jobs that are delivered after the due dates; the cost is proportional to tardiness, and (3) a cost proportional to earlobes for jobs that are completed prior to the due dates.

Miyazaki [1981] constructed a combined scheduling system composed of the due date assignment and the sequencing procedure for reducing job tardiness in job shops. He proposed that the process of determining the due dates can be divided into two major categories. Firstly, the customer has the initiative in determining the due dates; secondly, the manufacturer has the leadership in negotiating the due dates. He gave two formulae to give the mean and standard deviation of job flow time which are derived from the machine number, the load ratio, the required number of operations, and the mean and the standard deviation of processing times, which specify the characteristics of a job shop.

Tatsiopoulos and Kingsman [1983] explained two alternative approaches for determining planning values for manufacturing lead times to use in production planning and control systems. The first is to treat them as independent uncontrollable variables. It is then a forecasting problem with the emphasis on minimising the impact of the forecasting errors. The second approach puts emphasis on control and attempts to manage the average lead times to match predetermined norms. They conclude that the second one is the most appropriate but that it requires a close co-operation between the production and marketing function of the firm.

According to Baker [1984], says in actual shops, meeting due dates tend to be a more important criteria than minimal shop time (make span). The rules that do best are usually those that rely on due dates information in determining a job's urgency, although under

certain circumstances a processing time based SPT (shortest processing time) rule is also effective by virtue of its ability to accelerate the vast majority of jobs in the shop. He emphasises on three main types of approaches in determining priorities using due dates information

- Allowance based priorities
- Slack based priorities
- Ratio based priorities

Ragatz and Mabart [1984] proposed the due date management model dependent on work load information. They split it into three temporal categories : Jobs already in the system, The arriving jobs and Future jobs.

Vig and Dooley [1991] emphasises that due date assignment is an important element in production control affecting both timely delivery and the finished goods inventory. They presented two new dynamic due date assignment rules which utilise shop congestion information. The new rules estimate job flow time based on a sampling of recently completed jobs.

Tsuboneet al. [1992] presented an interactive due date management system for a job shop operation. They proposed that system can be used interactively by a production manager to set up alternative schedules whilst allowing for different priority scheduling rules under various production capacity levels.

Adam et al. [1993] described due date assignment procedures with dynamically updated coefficient for multi-level assembly job shop. They proposed a dynamic update approach to obtain the coefficients used in the traditional due date assignment procedures

of constant allowance (CON), total work content (TWK), and critical path processing time (CPPT)given by Adam et al. [1987]. The coefficient assigned to a given job reflects both the state of the shop at the time the job is processed and the characteristics of the job. This approach also provides the shop management with the ability to control the average job lateness.

Bagchi et al. [1994] addressed deterministic, nonpremptive scheduling of jobs that are immediately available for processing on a single machine. The jobs are portioned into several multi-job customer orders. They determined a due date for each customer order and scheduled all the jobs such that a total penalty function is minimised. The total penalty function of the sum of penalties for job earliness, for job tardiness. and penalties associated with lead times of customer order.

Raghu and Rajendran [1995] presented a real life study of a job shop manufacturing ball screws. They used three different methodologies for setting parameter coefficients based on a search algorithm, simulated annealing, and a combination of simulated annealing and regression analysis for due date setting in a job shop.

1.8 Organisation of Thesis

Chapter 2 deals with the problem definition and framework of the study. Problem and its environment .taken for this study is described in this chapter. Various solution approaches available are also described in this chapter. An approach to solve the problem, used in this study is also described in this chapter.

Chapter 3 deals with the system modelling. A discussion on the simulation model used in this study is also presented . Various environmental factors and job dispatching rules used for sequencing on the machines are also described in this chapter. A problem generator used for generating the problems is also described in this chapter.

Chapter 4 deal with the plant efficiency and effect of various job dispatching rules on the lead time of the parts. A model is developed for the calculation of the plant efficiency.

Chapter 5 deals with the lead time estimates . In this chapter we have developed models for the calculation of the lead times of the parts.

Chapter 6 deals with the conclusions arrived through this work and gives limitations of the study.

2

PROBLEM DEFINITION AND FRAMEWORK OF THE STUDY

2.1 Problem Definition

For this study we have considered a system environment in which the characteristics of the orders received are as follows

- A few jobs are to be processed during the production year having large no. of components.
- The completion time of the jobs is very large.
- components are processed in small batch sizes.

All the orders are available at the start of the production year. To deliver the products on their stated delivery dates a decision about the loading of the parts on the shop floor is to be made at the start of the production year. To decide the loading plan information about the lead time of the part is very essential. The lead time of a part comprises the total processing time of the part , the waiting time and the transportation time. The waiting time factor is a constraint on the accurate prediction of the lead times. Waiting time of a part is dependent on the shop loading conditions which varies day by day so the waiting time

involves a lot of uncertainties. Calculation of somewhat accurate lead times of the parts in quite advance (6 months or a year in advance) is the problem considered for this study.

2.2 Rationale of the Problem

In the intermittent production systems commonly known as job shops the main problem of concern with the basic planning data are the uncertainty and variation in the manufacturing lead times. These are at the heart of production scheduling. They have an importance for the production, marketing, and financial functions of the firm. In the present scenario in which meeting the customer delivery date is very important criteria, marketing people will be interested in the exact lead time of the product to quote the exact delivery dates to its customers. Finance people will also be interested in exact lead time for financial tide ups and obviously the production people are the most needy people of the lead time for capacity planning, order releasing and matching loading. So all the marketing financial and production activities are based on planning data about manufacturing lead time.

2.3 Solution Approaches:

Manufacturing lead time in intermittent production systems are often very long. Yet the actual processing time on all the machine through which the product has to pass are usually quite small. The manufacturing lead times are dominated by the transit times between operations. This is demonstrated by the speed with which urgent orders can be expedited through the system when required. Stommel [1976] showed that 90% of the total flow time is due to transit time, of which 85% is due to queuing, 3% due to quality control and 2% due to transportation only 10% is due to the actual processing operations. The problem of determining planning values for manufacturing lead time is mainly a

problem of discovering the underline factors that influence these inter operation transit times. Planning values for manufacturing lead times are clearly needed for each individual product for use in the formal planning system. Two distinct approaches have been taken for this problem.

- Emphasise the control of manufacturing lead times.
- Treat the manufacturing lead time as probabilistic.

2.3.1 Lead Time Management as a Control Problem [Tatsiopoulos and Kingsman (1983)]

In this approach the production system attempts to manage by actual lead times to match the predetermined planning values (norms). The actual lead times are still calculated. However this is to determined whether actions need to be taken to bring them to closer to the norms, rather then to update the planning data. The emphases is then placed on determining which level of planning affect lead time significantly and how these can be controlled to give average values to the desired norms. Lead time in company is a function of the backlog. Based on this truth a technique called input output control (IOC) started to become popular in the early seventies, as a consequence of the need to avoid the disastrous "lead time syndrome". The idea is roughly, to keep the amount of work load at each work centre at a constant level. Actual average work centre queen times are the mean times for all individual orders processed in one work centre over some period. According to IOC technique, actual and planning lead time must be the same. This require managing backlog of work in process at each work centre by controlling the input of new orders against output of completed work i.e. against capacity.

The main reason behind the built up of backlogs is the erratic input of the work at the work centres. Backlog acts as buffers for work input variations just as inventories are buffers against variation in demand. Thus backlog can be viewed as inventory of work. If the work supply to the work centre is very regular with respect to the time, the mean job flow time can be very low. In extreme cases such as conveyer belt production lines, the mean job waiting time can be zero even if capacity utilisation is practically equal to one. Thus mean flow time can be reduced by making the work supply more regular.

The lesson of IOC is fairly simple but not always understood in industrial practice.

- Input of work must never exceed the output (capacity).
- Input must be regular and smooth over time.

The main difficulty with the IOC method is controlling the input to secondary work centres. In a production line environment control of input is relatively simple and can be done by balancing the input against output from line. In a job shop with random work flow it is only the input to the first operation or "getaway" work centres that can be similarly controlled at the shop order release level. Controlling the inputs to the other secondary work centres is considerably more difficult to do. This is because their input in the combined output from many previous work centres are varies with product mix, routing sequences, and the foreman who controls the inputs to the queue of secondary work centres at the detailed dispatching level.

Another weakness of these approach is that they control only the output from the job pool by releasing the shop orders to the shop floor. They seem to ignore the input to the pool, as this is due to marketing decisions concerning the negotiation and quotations on customer's order.

2.3.2 Lead Time Management as a Forecasting Problem [Tatsiopoulos and Kingsman (1983)]

This approach starts from the stances that lead times are independent uncountable variables. The best that can be done is to have a formal planning system that reacts quickly to change and then adjust the planned values used to the actual lead time as often as is necessary. Lead time estimation is treated as a forecasting problem. The emphases is on accurate forecasting and then developing a planning routine to minimise the impact of forecast errors. Planning values for transit time between operations and safety time buffers are based on historical data and/or on forecasting the shop congestion in the shop. Two different approaches can be distinguished in estimating lead time.

- Use planning values based on historical data.
- Forecast lead times on the basis of actual shop loads.

The first approach is widely used in industrial practice. Many companies, especially those operating manual system, use a simple rule of thumb with regard to the inter operation time and usually allows a no. Of days or a whole week for the completion of an operation. Statistical analysis of past data can help in determining more accurate mean values for the transit time at each work centre. These mean values are the sum of the set-up, processing, queuing and break down time of all jobs that passed through the work centre over a long time period, divided by the no. of jobs. A more sophisticated version of this approach is the development of a transition matrix ("from-to") between all the work centres in the shop. The manufacturing lead time is given as the sum of set-up time, processing time and the transit between the work centres in the job sequence, as specified by the stored transition matrix.

The second approach is based on some factors that influence the manufacturing lead times. At the long term planning level, lead time are in aggregate determined by the factors like product structure, the production process and the layout of production facilities at the operational level. The factors that influenced inter-operation transit time have been classified by Heinemeyer [1974], into short term, medium term, and non-quantitative.

The short term influence factors are the batch quantities processing time, set-up time, priority rule, due date etc. The non-quantitative factors include the machine break-downs, missing tools, materials and labour absence. The medium term influence factors are by far the most important. These are

- Backlog of the work in the shop.
- Capacity planning methods.

The role of the backlog of work in the shop as a major factor influencing the lead times is apparent if the shop is viewed as complex queuing system while the relation of the backlog of work and transit times between operations is easily recognised. The role of capacity planning is often not clear.

2.4 Due Date Assignment Models

Due date of a job is the sum of its arrival time and an estimate of its lead time. Thus due date of a part j can be represented as :

$$d_j = r_j + T_j$$

where dj = the due date of the part j.

r_j = the arrival time of the part j.

T_j = the lead time estimate of that part j.

As discussed previously, due to uncertainties, determination of lead time is the factor that gives rise to various due date assignment procedures. The procedures discussed in the literature may be classified into three categories.

- The allowance of individual jobs is set equal to a constant (CON) representing the average lead time of a job in the shop. A better estimation then CON is SLK where equal allowance is given to its processing time. Mathematically these are represented as :

  CON : $T_j = K$ (Constant flow allowance)

  SLK : $T_j = P_j + K$ (equal slack)

  where Pj = total processing time of part j,

  K = parameter coefficient, chosen differently for each rule.

- The allowance of a job is in proportion to its total processing time (TWK) or in proportion to its no of operation (NOP), or both. Mathematically these are represented as :

  NOP : $T_j = Km_j$ (proportional to the number Of operation)

  TWK : $T_j = KP_j$ (Proportional to total work)

  PPW : $T_j = P_j + Km_j$ (processing plus waiting time)

  where m_j = Number of operation for job j,

- An allowance in proportion to the work content of the job and the work load in the shop. This is represented as :

  $T_j = K_1$. (sum of processing time of all operations)

$+ K_2$. (sum of the total work at all work centres)

where K_1, K_2 are the parameter coefficients

2.5 Framework of the Study

Because of the various drawbacks of the input & output approach lead time management problem is considered as a forecasting problem for this study. The various factors which influence the lead time of a part are given below.

- The characteristic of work load in the shop (i.e. the routing and the operation processing times of the job).
- The operating decision rule (job dispatching rule) which control the scheduling of production in the shop.
- The shop structure (i.e. the no. of workers and machines present).

The shop congestion (i.e. the information about the remaining work of the parts loaded in the shop).

The first factor which requires the information about the no of operations and their processing times is fixed i.e. it will not change with time. The second factor that is the job dispatching rule is an organisations policy to sequence the jobs on the machines which is also not changing during production. The third factor that is shop structure is also fixed unless the organisation is having a dynamic shop structure (i.e. the case in which the management can take can take the strategic decision about increasing or reducing the shop capacity depending upon the shop loading conditions). The fourth factor which is the shop congestion is a time dependent factor. So it is impossible to predict about the shop congestion in 6 months or a year in advance. The factors which involve uncertainties such

as machine break-downs, labour absenteeism, arrival of an immediate priority part etc also worsen the situation. To develop a model for the calculation of lead times of a part in quite advance we have to rely upon the fixed factors. To take care of the fourth factor we consider the machine utilisation. The following factors which influence the lead time of a part are considered for this study.

- The total number of operations of the part.
- The total processing time of the part.
- The utilisation of the maximum utilised machine (among the machines that are on the route of the part)
- A rule efficiency factor (To take care of the different job dispatching rules followed by different organisations).
- A shop factor (To take care of the various unforeseen factors such as machine break-down , Labour absenteeism , arrival of an immediate priority part etc.).

The model considered for this study is given below.

Lead Time = (k1 * No of operations + k2 * Total processing time of the job + k3 * Average percentage utilisation) * Rule efficiency factor * shop factor .

To calculate the parameters k1, k2 , k3 & efficiency factors we need the actual lead times of the parts . In a purely deterministic system , where arrival and processing times are known in advance, not only for the jobs in question , but for all current and future jobs as well, it is possible by simulation to determine precisely (for a given set of rules of priorities and scheduling) when the job will be completed. So a simulation model is

developed for job shop environment for this study which will be described in detail in the next chapter.

After simulating the lead times regression analysis is used to calculate the coefficients used in the lead time model.

3

SYSTEM MODELING

3.1 Simulation

The term "job shop" or "jobbing production" denotes a type of production in which the work is of such a diverse nature that batching or flow lining is impractical. Rather the work must be treated as a series of individual jobs with its on peculiar routing among the machine. At any one time in the factory there will be a vast number of jobs in various stages of progress. They will be in competition with each other for time on the available machines. There will thus the many possible ways of sequencing the work of the factory. The rules or principles used to decided on work sequence will affect the utilization of the plant as whole, the volume of work in progress, and the punctuality with which work is completed related to due dates quoted to customers.

The problem of determining the best rule to use is clearly a formidable one, due to the complexity of the operations and the number of criteria which have to be satisfied. One approach to this type of problem is to define all the possible states that the system can attain, and write down mathematical expressions for the probability of each states in terms of the probability of adjacent states and the probability of transition from these. A solution to these equations, if achievable, will gave the values of all the states probabilities and hence a complete solution to the problem. However, in most of the situations the possible

number of states is enormous. Moreover there are enormous number of ways of reaching any given state from adjacent state. Hence this method becomes impossibly cumbersome.

The alternative is to play out all the movements in time sequence and record the occurrences of the actual states of the model system as the run progresses. This is of-course the simulation approach. The simulation model we consider in this work is discrete/event simulation.

3.1.1 Discrete Event Simulation

Discrete-event simulation concerns the modeling of a system as it evolves over time by a representation in which the state variables change only at a countable number of points in time. These points in time are the ones at which events occur, where an event is defined to be an instantaneous occurrence which may change the state of a system.

3.1.2 Time Advance Mechanisms

Because of the dynamic nature of discrete event simulation models, we need to keep track of the current value of simulated time as the simulation proceeds, and we also need a mechanism to advance simulated time from one value to another. We call the variable in a simulation model which give the current value of simulated time the simulation clock. Historically two principal approaches have been suggested for advancing the simulation clock, namely, next event time advance and fixed increment time advance.

3.1.2.1 Next Event Time Advance

With the next event time advance approach, the simulation clock is initialized to zero and the time of occurrences of future events are determined. The simulation clock is then

advanced to the time of occurrence of the most imminent(first) as these future events, at which point the state of the system is updated to account for the fact that an event has occurred, and our knowledge of the time of occurrence of future event is also updated. Then the simulation clock is advanced to the time of the (new) most imminent event, the state of the system is updated, and future events are determined etc. This process of advancing the simulation clock from one event time to another is continued until eventually some prespecified stopping condition is satisfied.

3.1.2.2 Fixed Increment Time Advance

With this approach, the simulation clock is advanced in increment of exactly Δt time units. After each update of the clock, a check is made to determine whether any events should have occurred during the previous interval of length Δt. If one or more events were scheduled to have occurred during this interval, these events are considered to occur at the end of the interval and the system state(an statistical counters) are updated accordingly. This approach is used for this work. Flowchart is shown in *fig 3.1*

3.2 Methodology for this Study

Since no promising analytical techniques exists for the analysis of dynamic job shops, computer simulation is chosen as the research method of this study. Past research of job shop production systems has been largely concern with the dispatching and due date assignment aspects of the job shop. In this study some environmental factors such as machine break down, labour absenteeism, and handling of an immediate priority item is also included. Section 3.3 describes the operating decisions that are varied to produce the experimental design of study.

3.3 Variable Operating Decisions

There are two categories of factors that are expected to have an impact on the performance of a job shop.

- Controllable factors
- Environmental factors

3.3.1 Controllable Factors

Controllable factors are those over which the management has full control. The various controllable factors used in this study are

- Dispatching rules for machine loading and transportation(part scheduling)
- Strategies for machine selections

3.3.1.1 Part scheduling

The following are the types of decisions to be taken for scheduling the parts.

1. Loading of part in the shop.
2. Selection of jobs for machining.
3. Selection of jobs for transportation.

3.3.1.1.1 Loading of Parts In Shop

Parts are loaded into shop according to their loading day. Any number of parts can be loaded in the shop. There is no constraint over the maximum number of jobs to be in the shop.

3.3.1.1.2 Selection of Jobs For Machining

Twelve dispatching rules are considered for loading of the machine. User can select appropriate dispatching rule. A brief discussion of these dispatching rules is presented.

FCFS (First come first serve):

The most natural ordering is that the first job into the shop get worked on first. This rule is called First come first serve. It is appealing because it seems to be the fairest rule to follow. However by at least one measure, It is unfair because it penalizes the average customer more than other sequence rule.

SPT (Shortest processing time)

It is a processing time based rule. According to this rule, priority will be given to those parts which will have shortest processing times. The SPT has the ability to accelerate the vast majority of jobs in the shop. SPT sequencing is often effective at meeting due dates, even though it does not explicitly use due date information.

EDD (Earliest due date)

It is a flow allowance based priority rule. A flow allowance is the time between its release date and its due date. If the parts are at time t, the remaining allowance of the jobs may be expressed as

$$a_j(t) = d_j - t$$

where $a_j(t)$ is the remaining allowance at time t.

d_j is the due date.

Under the EDD rule, the urgency of a job is related to its remaining allowance. EDD rule give the priority to the parts having smallest $a_j(t)$.

MST (Minimum slack time)

It is a slack based priority rule. a job's slack is its remaining allowance adjusted for remaining work. The slack for job j is

$$S_j = a_j(t) - P_j$$

where S_j is slack time.

P_j is the time required by the remaining operations of job j.

MST rule gives priority to those parts which are having smallest S_j. The intuitive justification for MST rule is that when two jobs have the same allowance, the longer job is more urgent because its due date allows less delay. One structural problem with slack based priorities is that by "netting out" remaining work against remaining allowance, MST priority incorporates some anti-SPT scheduling compared to EDD priorities, at least among jobs with similar due dates.

SCR (Smallest critical ratio)

It is ratio based priority rule. In this rule urgency is measured by the ratio of remaining allowance and remaining work(rather than their difference, as in MST). The simplest form of ratio for the job j is

$$r_j = a_j(t) / P_j .$$

where r_j is the ratio.

Some times remaining work is augmented by standard queue allowances in the critical ratio. Priority based on smallest critical ratio(SCR) have some practical feeling that the

... whether the job is running late. However, negative

ratios are difficult to interpret, and SCR is open to criticism that, like MST, it includes some anti SPT behavior at the margin.

Another factor measuring the urgency is the number of operations remaining on a job. When two jobs have the same remaining allowance and remaining work, the job with larger number of operation is intuitively more urgent because it will encounter more opportunities for queuing delays, other things being equal. This reasoning has led to priority indices based on remaining allowance per operations and slack per operations.

A/OPN (Allowance per operation)

It is also a ratio based priority rule. In this rule urgency is measured by the ratio of remaining allowance and remaining number of operations. The ratio r_j for the job j is

$$r_j = a_j(t) / OPN$$

where OPN is the number of remaining operations.

S/OPN (Slack per operation)

In this rule urgency is measured by the ratio of remaining slack and remaining number operations. The ratio r_j for the job j is

$$r_j = S_j / OPN$$

Although these rules have performed well in some research experiments, they along with SCR, have some practical drawbacks. One problem is that ratio priorities may work in wrong direction when their numerators are negative. Among jobs with negative slack, the job with minimum slack per operation might not be a logical dispatching choice. Secondly, the ratio priorities are dynamic. As the two jobs wait in queue their relative priorities may

change. This feature could be perplexing in practice, although dynamic priorities are often considered to be desirable.

Another way to recognize the number of remaining operations is to utilize operation milestones. After a job's due date is assigned, it is possible to set milestones in place to show when each operation should complete if the job is to progress smoothly towards on time completion. These milestones are called operation due date, and they essentially break up a jobs flow allowance into as many pieces as the number of operation in the job. These pieces then play the role of operation flow allowances, and they pace the job through the shop.

once the operation due dates have established, jobs can be dispatched by priority rule that can utilize the operation processing time and operation due dates. The following three rules are based on operation due dates and operation processing times.

MOD (modified operation due date)

The modified operation due date rule dynamically modifies the due date. It uses ODD rule for selection of the jobs when there is a possibility of finishing the jobs on time, afterwards it selects the jobs with minimum total work remaining. Symbolically MOD can be represented as

$$d_j^* = \max[odd_{ji}, t + T_{ji}]$$

where d_j^* represents the MOD of the job j.

t is the time.

odd_{ji} is the operation due date of i^{th} operation for job j.

T_{ji} represents the processing time of i^{th} operation of the job j.

In MOD rule the priority is given to those job which are having minimum modified operation due date.

OST (operation slack time)

This gives the priority to the parts according to their operation slack times. Parts having minimum operation slack time are given priorities.

OCR (operation critical ratio)

This is dependent upon the ratio of the remaining allowance per operation to the processing time of that operation. Parts having the less ratio are given priorities.

CR+SPT (combination of CR and SPT)

The CR-SPT rule uses an operation due date for its K^{th} operation defined by

$$d_{jk}^{*} = \max[T+\beta(T)\, t_{jk} \;,\; T+t_{jk}]$$

For a job j with n_j operations and whose K^{th} operation is imminent at time T, the critical ratio becomes

$$\beta(T) = a_j\,(T) / \sum_{j=k}^{n} t_{ij}$$

Where a_j (T) is the allowance .

t_{ij} is the processing time of j^{th} operation of job i.

d_{jk}^{*} is the due date of K^{th} operation of job j.

t_{jk} is the processing time of the K_{th} operation.

It is worth pointing out that when a job first arrives in the shop the CR+SPT rule assign an operation due date for its first operation which is the same as modified operation due date from MOD rule.

S/ RPT

This rule uses the slack per remaining processing time ratio γ (T), which is defined as

$$\gamma(T) = s_i(T) / \sum_{j=k}^{n} t_{ij} = \beta(T) - 1$$

$$d_{jk}^{*} = \max[T+\gamma(T)\, t_{jk}\ ,\ T+t_{jk}].$$

where s_i (T) is the slack.

γ (T) is the slack per remaining processing time ratio.

β(T) and t_{jk} are defined above.

3.3.1.1.3 Selection of Jobs For Transportation

The following steps are involved in the selection of jobs for transporting.

1. If any part of immediate priority is waiting for transportation ,select the job for transportation.

2. select the jobs for which the machines for the next operations are idle.

3. If none of the machines is idle select the jobs according to EDD rule.

3.3.1.2 Machine Selection

The following steps are involved in the selection of machines for the job to visit.

1. If the part is of immediate priority ,select the machine for which processing time is shortest.

2. Among the machines which can process the selected jobs, select the machine with minimum queue.

3.3.2 Environmental Factors

Environmental factors are those factors over which the management have no control. The various environmental factors considered in this study are described below.

3.3.2.1 Machine Break-Down

Machine break-downs are inevitable in any manufacturing shop. so this factor is included in this study . Machine break-downs are generated randomly. A negative exponential function is used to generate the break-downs. Negative exponential function is used because it is memoryless function, so the break-down of one machine does not affect the break-down of the next machine in any way. Different level of break-downs are used in this study to monitor the performance of the shop under different levels. The down time of the machines for repair are also generated using random number. We generate a random number between 1 to 25 and this number is assigned as the down time for the machine which got break down. We can vary the machine break-down levels by varying the time between the two consecutive break-downs. Any other distribution function can be incorporated for this purpose by making appropriate modifications in the program. The down time of the machines for repair are also generated using random number.

3.3.2.2 Arrival of An Immediate Priority Part

If these type of items arrive in the shop then they disturb whole the shop. So this factor is used in this study to monitor the performance of the shop under the arrival of immediate priority item. A Poisson distribution function is used for the arrival of an immediate priority item. The performance of the shop can be monitored at different levels of arrival by varying the probability of an immediate priority part to come in the shop.

3.3.2.3 Labour Absenteeism

Labour absenteeism is a major problem in any manufacturing firm. So this factor is also included as a part of this study to monitor the shop performance under the influence of this factor . Labour absences are generated randomly. A negative exponential distribution function is used, however any other function can also be incorporated.

3.4 Performance Measures

The performance measures are related to the two entities . These entities are : (i) jobs , (ii) machines . Both the entities have different measures of performance.

(i) Jobs : Statistics for the simulation model are collected for the following performance criteria : mean flow time, mean tardiness, root mean square of tardiness, and no of tardy jobs.

Job flow time is the common measure of job shop performance with practical significance as an estimate of work in process inventory. However job tardiness results are emphasized in this study because of their practical significance to production managers. Typically tardiness is represented by mean tardiness and no of jobs tardy . However a dilemma arises when comparing systems with low mean tardiness and high no of tardy jobs. The root mean square of tardiness calculations is designed to solve this problem. Each job tardiness figure is squared , then summed over the number of tardy jobs before taking the square root. This value tends to penalize systems with a few jobs that are very late more than those with many jobs that are a little late . Practitioners have shown a preference for this logic in assessing the impact of late jobs.

Performance Measures	Symbols	Definition
Mean Flow time	$\bar{F}$	$\sum(p_j - r_j)/N$
Mean Tardiness	$\bar{T}$	$\sum \max(0, L_j)/N$
Root Mean Square of Tardiness	RMST	$(\sum \max(0, L_j)/N)^{1/2}$
No of tardy jobs	NT	NT

3.5 Inputs To The Simulation Model

The various inputs to the simulation model are described below.

1. Requirement File

Req.dat file is used as the requirement file. This file consist of

- Order no. of the job.
- Part no. contained in the order.
- Parent part no. (i.e. the assembly no. in which this part is to be assembled).
- Number of parts required for this part(if it is on assembly or sub-assembly level).
- Loading day of the part.
- Delivery day of the part.
- Mark whether the part is an immediate priority part or not.

2. Process File

Part.dat file is used as the process file for the part. This file is actually the process sheet of the part. This file consist of

- Total number of operations to be performed on the part.
- Machine no. for a particular operation number.
- Processing time for this machine.
- Alternate machine for this part.
- Processing time for alternate machine.

3. Job dispatching rule followed by the company.

4. Probabilities of occurrences of various environmental factors (i.e. machine break downs, labour absenteeism and arrival of an immediate priority part).

3.6 Event Description

In the model that has been developed, the following are the events that cause a change in the system status

1. Loading of the job from requirement file to the event list.
2. Arrival of a job for processing on a machine.
3. Departure of a job from a machine after the completion of an operation.
4. Transportation of a job.
5. Arrival of an immediate priority part.
6. Machine break-down.

7. Labour absence.

3.6.1 Arrival of a New Job from Requirement File to Event List

At the arrival of this event the job is added to the event list. Each day REQ file is searched if there is any component for which loading day equals the current day, if it equals then the type of event is set equal to zero and part is added to the event list.

flow chart is shown in *fig 3.2*

3.6.2 Arrival of a Job on a Machine for Processing

STEP 1 : Determine the machine for the arriving part on which the processing is to be done.

STEP 2 : Check whether the first machine running or not. If the is running GO TO STEP 5 , else GO TO STEP 4.

STEP 3 : Check whether the alternate machine is running or not . If machine is running GO TO STEP 4 , else GO TO STEP 11.

STEP 4 : Determine the alternate machine. If there is any alternate machine GO TO STEP 3 .

STEP 5 : Check whether the machine is idle or not. If machine is idle GO TO STEP 6 , else GO TO STEP 7.

STEP 6 : Load the part on machine. GO TO STEP 8.

STEP 7 : Check whether the part is an immediate priority part or not. If it is an immediate priority part GO TO STEP 9, else GO TO STEP 10.

STEP 8 : Schedule the departure event for the part. GO TO STEP 12.

STEP 9 : Add the part at start of the queue. GO TO STEP 12.

STEP 10 : Add the part at the appropriate place in the queue according to the rule followed by the shop.

STEP 11 : Add the part to the machine for which break-down is less .

STEP 12 : Finish.

Flow chart is shown in *fig 3.3*

3.6.3 Departure Event of the Part after the Processing is Over

STEP 1: Determine the machine from which the departure of the part will be.

STEP 2 : Remove the part from the machine.

STEP 3 : Check whether the machine has become idle or not. If machine has become idle GO TO STEP 4 , else GO TO STEP 5 .

STEP 4 : Set the machine status free . GO TO STEP 7.

STEP 5 : Load the first part from queue to the machine.

STEP 6 : Schedule the departure event for that part.

STEP 7 :Check whether the processing of the departing part is over. If the processing has completed GO TO STEP 9, else GO TO STEP 8.

STEP 8 : Send the part to the transportation center. GO TO STEP 10.

STEP 9 : Remove the part from the shop. Calculate the time spent by the part in the shop lateness of the part etc.

STEP 10 : Finish.

Flow chart is shown in *fig 3.4*

3.6.4 Transportation of The Part

STEP 1: Check whether an immediate priority part is waiting for transportation or not. If yes GO TO STEP 4 , else GO TO STEP 2.

STEP 2 : Check whether there is any part for which the machine on the next operation is idle or not . I f Yes GO TO STEP 4 , else GO TO STEP 3 .

STEP 3 : Choose the part according to the EDD rule.

STEP 4 : Remove the part from transportation center.

STEP 5 : Add the arrival event for the transported part to the event list.

STEP 6 : Finish.

Flow chart is shown in *fig 3.5*

3.6.5 Machine Break-Down

STEP 1: Determine the machine which got break-down.

STEP 2: Is machine already under break-down. If yes GO TO STEP 10, else GO TO STEP 3.

STEP 3 : Check whether the machine is idle or not. If m/c is idle GO T STEP 10 , else GO TO STEP 4 .

STEP 4 : Check whether the m/c is having any queue or not. If the m/c is having queue GO TO STEP 5 , else GO TO STEP 9.

STEP 5 : Check whether the part in the queue is having any alternate machine. If part is having alternate machine GO TO STEP 6 , else GO TO STEP 8.

STEP 6 : Is the break-down time and waiting time of the part on the first machine is greater then the waiting time on the alternate machine ?. If it is greater GO TO STEP 7 , else GO TO STEP 8.

STEP 7 : Load the part on the alternate machine. GO TO STEP 8.

STEP 8 : Have all the parts in the queue been checked ?. If not GO TO STEP 5 , else GO TO STEP 9.

STEP 9 : Update the departing time of the part loaded on the machine in the event list.

STEP 10 : Finish.

Flow chart is shown in *fig 3.6*

3.6.6 Arrival of An Immediate Priority Part

STEP 1: Check whether the part is loaded on any machine or not. If part is in the shop GO TO STEP 5 , else GO TO STEP 2.

STEP 2 : Is part loaded on more then one machine. If part is loaded on more then one machine GO TO STEP 3.

STEP 3 : Choose the part whose more number of operations has been completed .

STEP 4 : Assign the loaded part to the priority order. GO TO STEP 5.

STEP 5 : Load the fresh part in the shop.

STEP 6 : Finish.

Flow chart is shown in *fig 3.7*

3.6.7 Labour Absence

STEP 1: Determine the machine of which the labour is absent.

STEP 2: Update the departure event of the loaded part on the machine by the no of days, the worker will absent.

STEP 3: Finish.

Flow chart is shown in *fig 3.8*

3.7 Outputs Of The Simulation Model

The various outputs that can be obtained from the simulation model are described below.

1. Lead time of various parts.
2. Average lead time of the shop.
3. Average lateness of the shop .
4. RMS lateness of the shop .
5. Number of tardy jobs .
6. Average utilisation of each machine .
7. Average waiting time on each machine .

3.8 Problem Generator

As we have mentioned that we require two files, as the input to the simulation model. One is the requirement file and other is the process file (containing the routing sequence of the parts). Both of these files are generated by using random numbers. All the random numbers are generated using the generator available on the HP 9000 UNIX system. File generator.c is used for generating the problem.

3.8.1 Requirement File Generation

In simulation model we have used req.dat as the requirement file. We have assumed that the shop hypothesized for this study can process 500 different part types, however there is no restriction on the number of part types to be processed in the shop. 500 part types are divided into three groups. Parts numbered form 400 to 500 are at assembly level, form 200 to 400 are at sub-assembly level and from 1 to 200 are at part level. Inputs to the generator used for generating the requirement file are

- The number of jobs.
- The number of parts contained in the job.

A random number is generated between 1 to 1000 and is assigned as the order no. of the job to be loaded in the shop. Then a random number is generated for this order and is assigned as the loading day for that particular order. Then for each assembly to be contained in a order a random number is generated between 400 to 500 . Then a random number is generated and is assigned as the number of sub assemblies required for the assembly. A random number is generated between 200 to 400 to decide the sub assemblies required for the assembly. After deciding the sub assemblies , we generate the number of

parts required for the sub assemblies and a random number is generated between 1 to 200 to decide the part nos. required for the sub assembly. Floe chart is shown in *fig 3.9*

3.8.2 Process Data Generation

Part.dat file is used as the process file in our simulation model. Process file is generated for a specified number of parts. We have generated this file for 500 different parts. Four types of process sheets can be generated by the generator, which are given below.

- Parts having no flexibility and an inspection center on the rout after all operations.
- Parts having no flexibility and an inspection center on the rout after each operation.
- Parts having an alternate machine for each operation and an inspection center on the rout after all operation.
- Parts having an alternate machine for each operation and an inspection center on the rout after each operation.

The following steps are taken while generating the process file

1. **Generation of Number of Operations**

A random number is generated between 2 to 20 and this number is assigned as the total number of machining operations for the part. If the parts is having inspection after all operation then total number of operations for the parts will be the number of machining operations increased by one and if the parts are having inspection after each operation then the total number of operation for the part will be double of the number of machining operations for that part.

2. Machine Selection

After deciding the total number of operations for the part a machine is to be generated for each operation. The chances for a machine to be selected depends upon the group to which the machine belongs. Machines are divided into five groups . Machines numbered from 1 to 10 are in first group, from 11 to 20 are in second group, from 21 to 30 are in third group, from 31 to 40 are in fourth group and from 41 to 50 are in fifth group. Machines in each group have different probabilities of selection. A random number between 1 to 100 is generated, if number is between 1 to 10 then a machine from first group is selected, if number is between 11 to 30 then a machine from second group is selected, if number between 31 to 50 then a machine from third group is selected , if number is between 51 to 80 then a machine from fourth group is selected and if number is between 81 to 100 then a machine from fifth group is selected. If a machine is assigned to an operation then it can't be assigned to the next operation for that part, however the machine can be assigned to other operations on the rout of that part. It means that no two subsequent operation can be done on the same machine, however the part can see the same machine more then once on its rout. If the part is having an alternate m/c for operation , an alternate m/c is also generated for the part .

3. Processing Times Generation

Process time for each operation is also generated randomly . A random number between 2 to 10 is generated and is assigned as the process time for that operation. For inspection time a random number between 1 to 3 is generated.

3.9 Interactive Scheduler

In this chapter we described a simulation model used in this study. In this simulation model we assumed that same dispatching rule is to be used for sequencing on all machine. Further all the uncontrollable factors are incorporated in this study by generating randomly the probabilities of these factors. The way of including the factors by using the probabilities doesn't represents truly the occurrences of these events. Further in some environments it is quite possible to use different dispatching rules for different machines and it is quite logical to use different dispatching rules for a bottleneck machine and a least utilized machine. All these difficulties may be overcome by developing a interactive system. According to Gantt and Young[1985] interactivity goes beyond just input or editing of data. It allows the person to observe the program execution and to interact with the system to provide more intelligent results. One form of this interaction is found in graphical animation , by which a user can see movements in a dynamic system and judge whether they are realistic . Such interectivity provides;

1. Model demonstration.
2. Control of logic.
3. Recognition of undesirable system states(bugs).
4. Simplifying of variations
5. Supervising alternative runs.

In this work we have developed a interactive scheduler. The scheduler have the following features.

- The interactive scheduler aids a user in selecting different job dispatching rule for different machines. When the processing of a part is over then the system asks the user about the rule to be followed to load a part from the queue on the machine for processing.
- Each day the scheduler asks the user whether there is any immediate priority part arrival or not. if there is any, scheduler asks the user part no for which the immediate priority order is placed.
- Each day the scheduler asks the user whether there is any break down on that day or not. If there is any, then scheduler asks the user to enter the machine no. which goes down and the down time of the machine.
- Each day the scheduler asks the user whether any worker is absent on that day or not. If any worker is absent the scheduler prompts the user to enter the machine no. of which the worker is absent and the days for which the worker is absent.

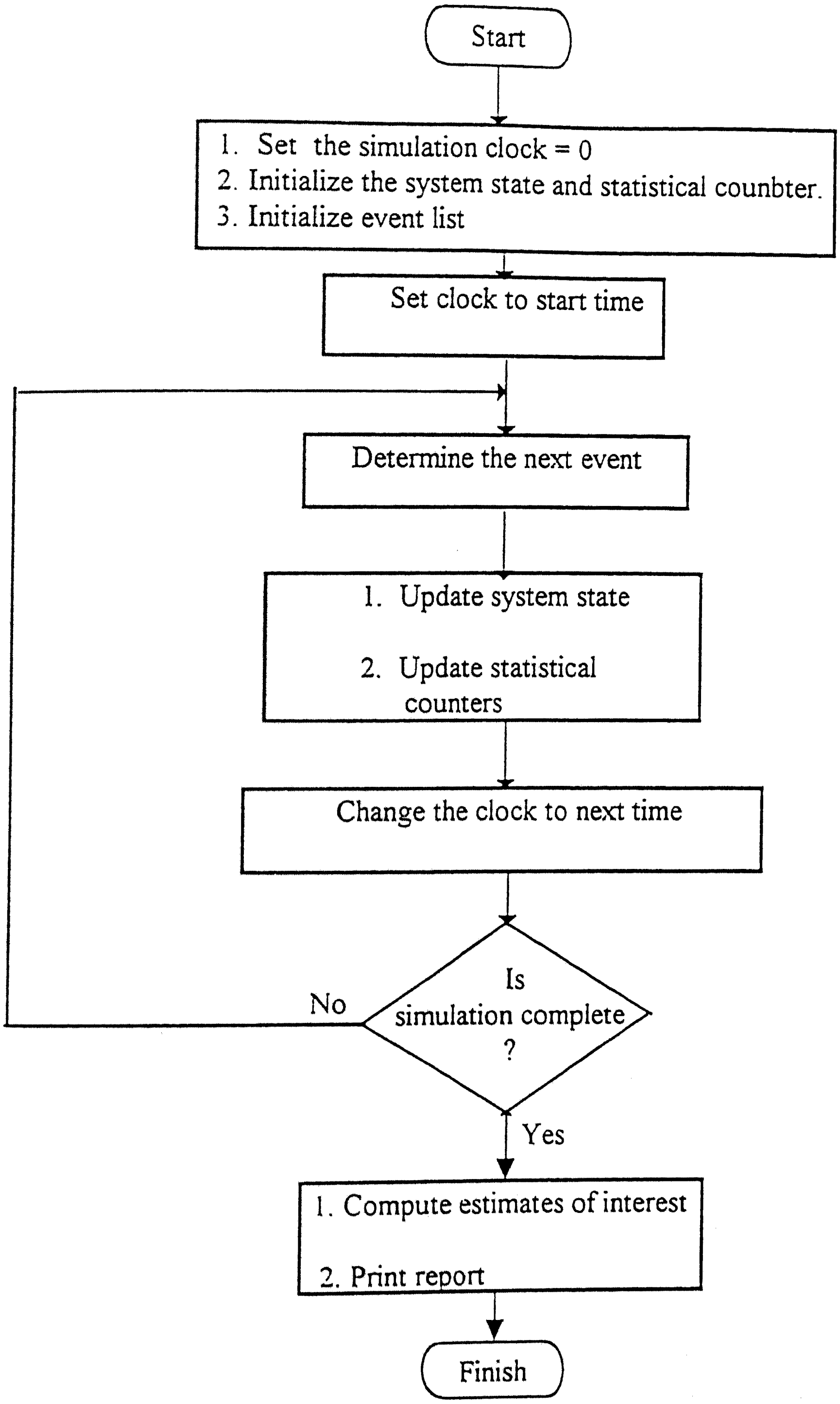

Fig : 3.1 Flowchart for fixed time advance mechanism

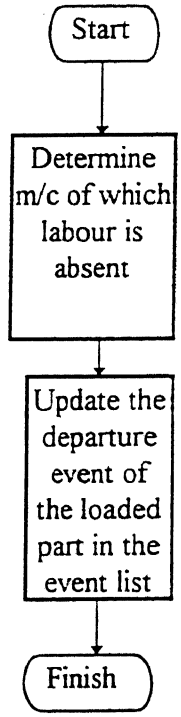

Fig : 3.8 Labour Absence

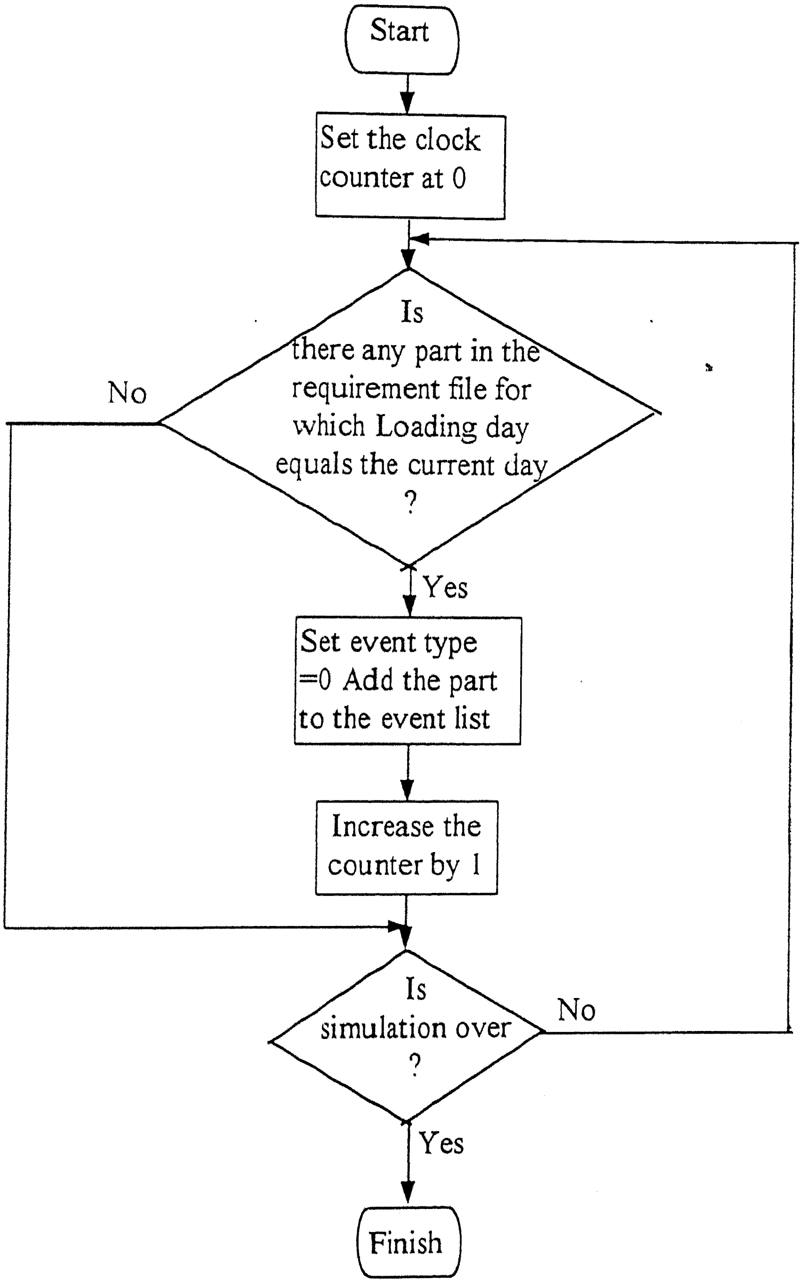

Fig 3.2 Loading of the part from the requirement file to the event list

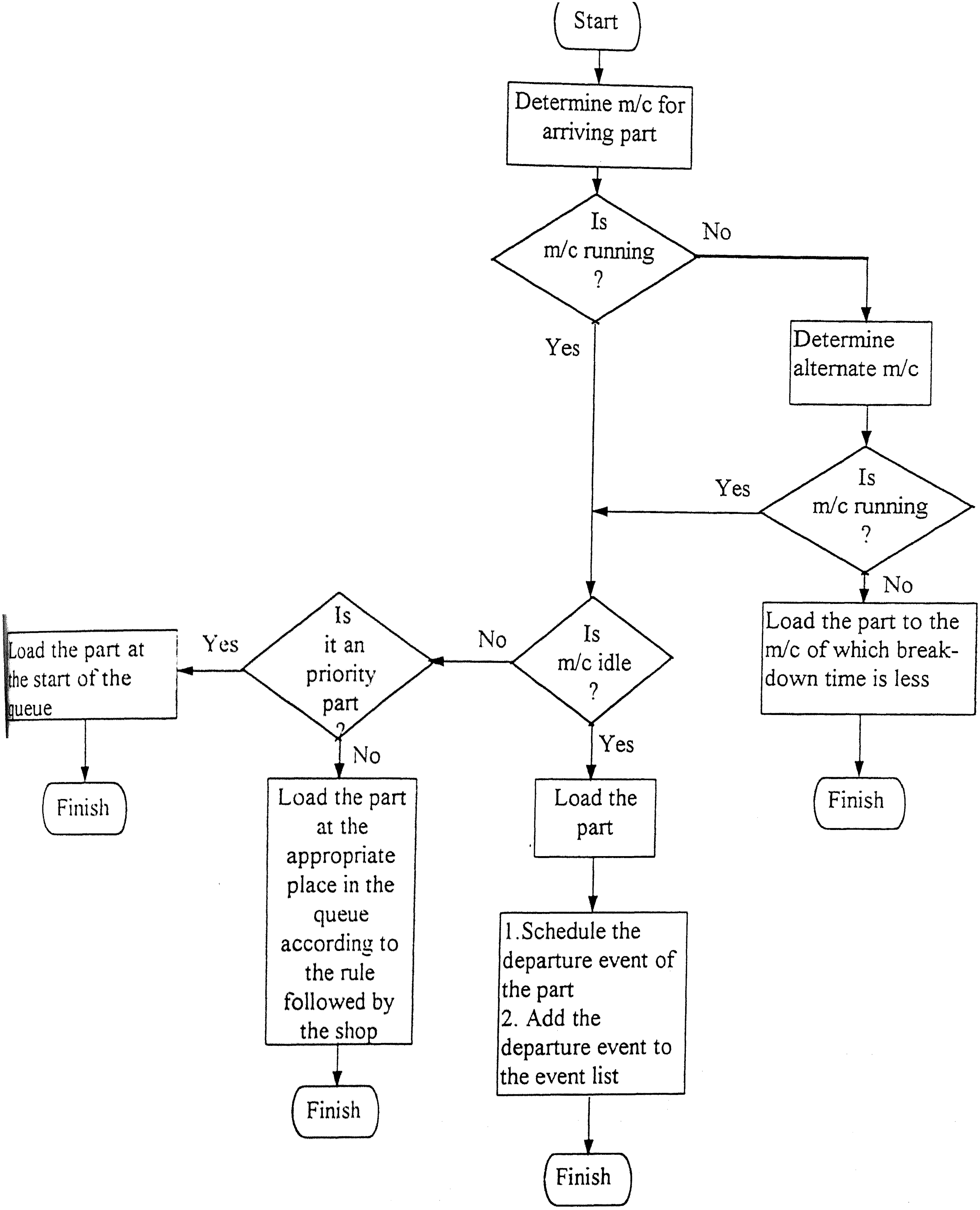

Fig : 3.3 Arrival Event of a part for processing on a machine.

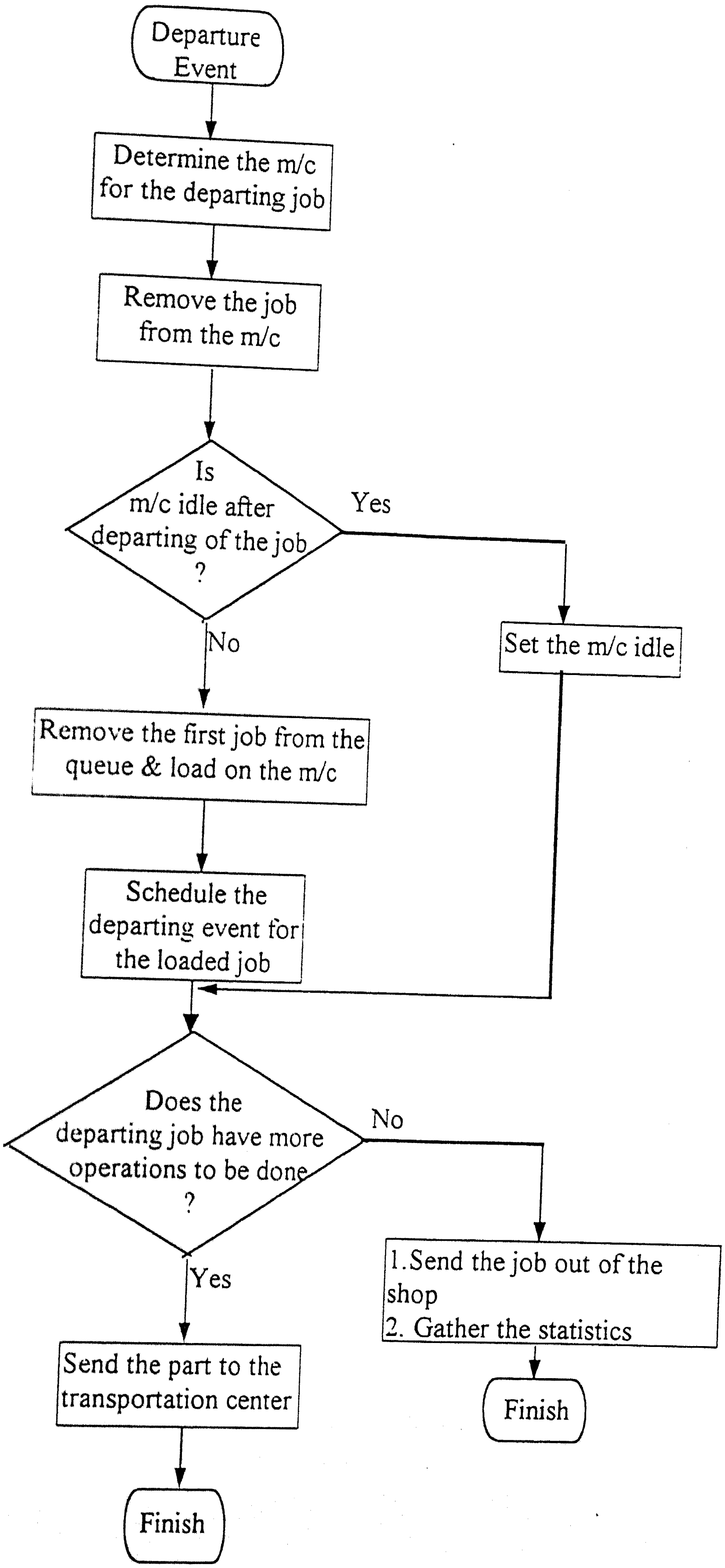

Fig 3.4 Deparure of a part after the completion of an operation

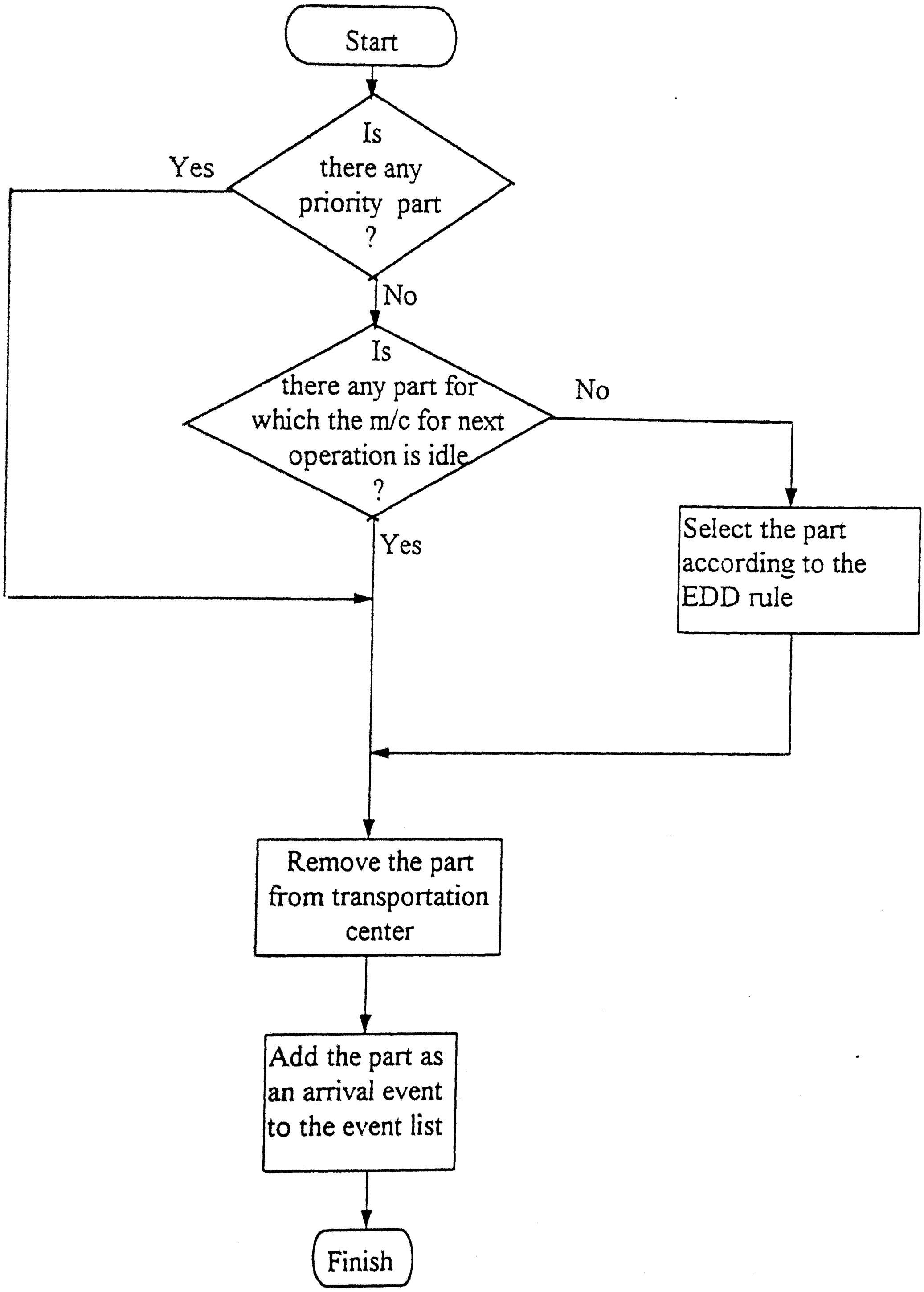

Fig : 3.5 Transportation of a part For the next operation

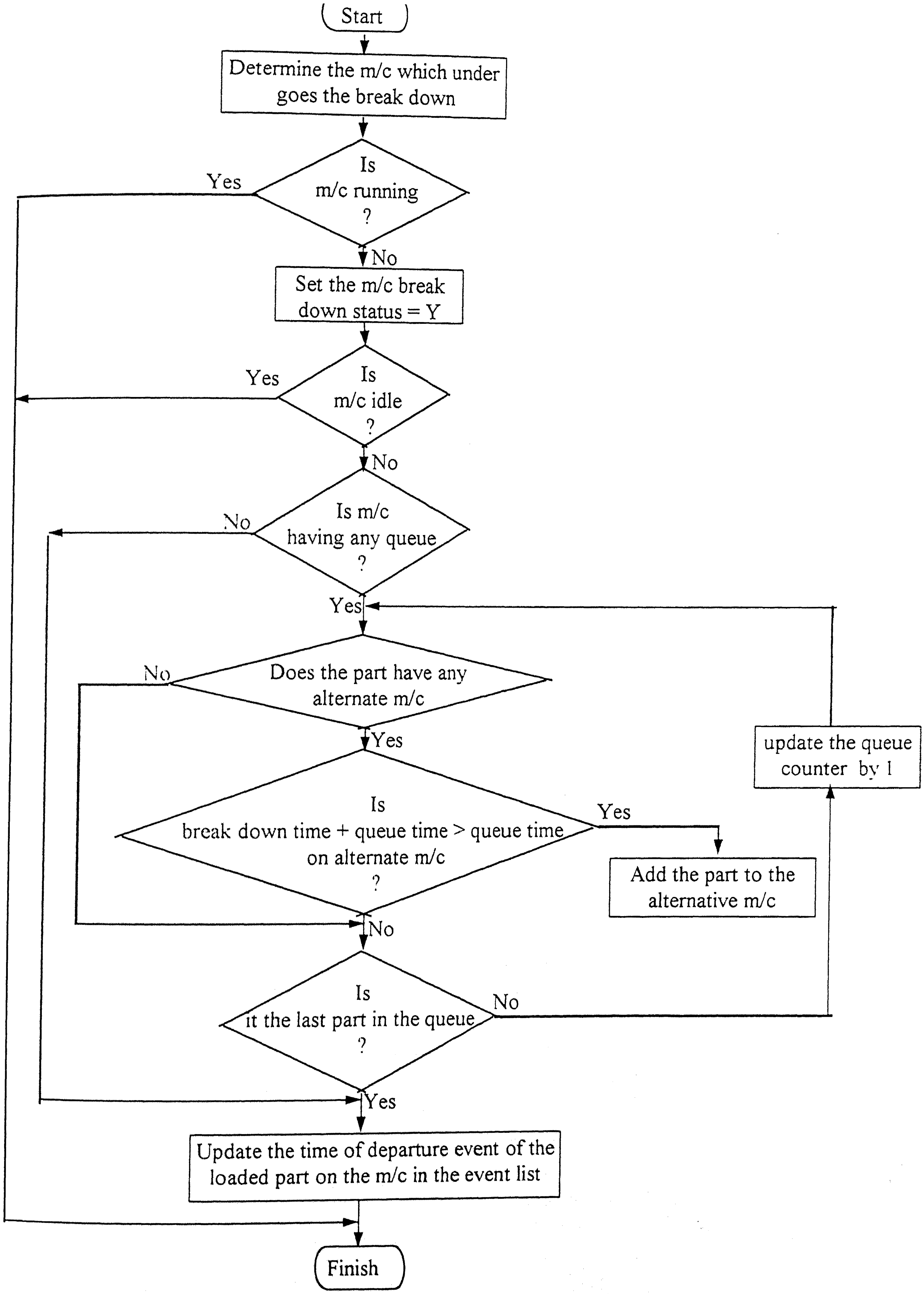

Fig : 3.6 Machine Break-Down

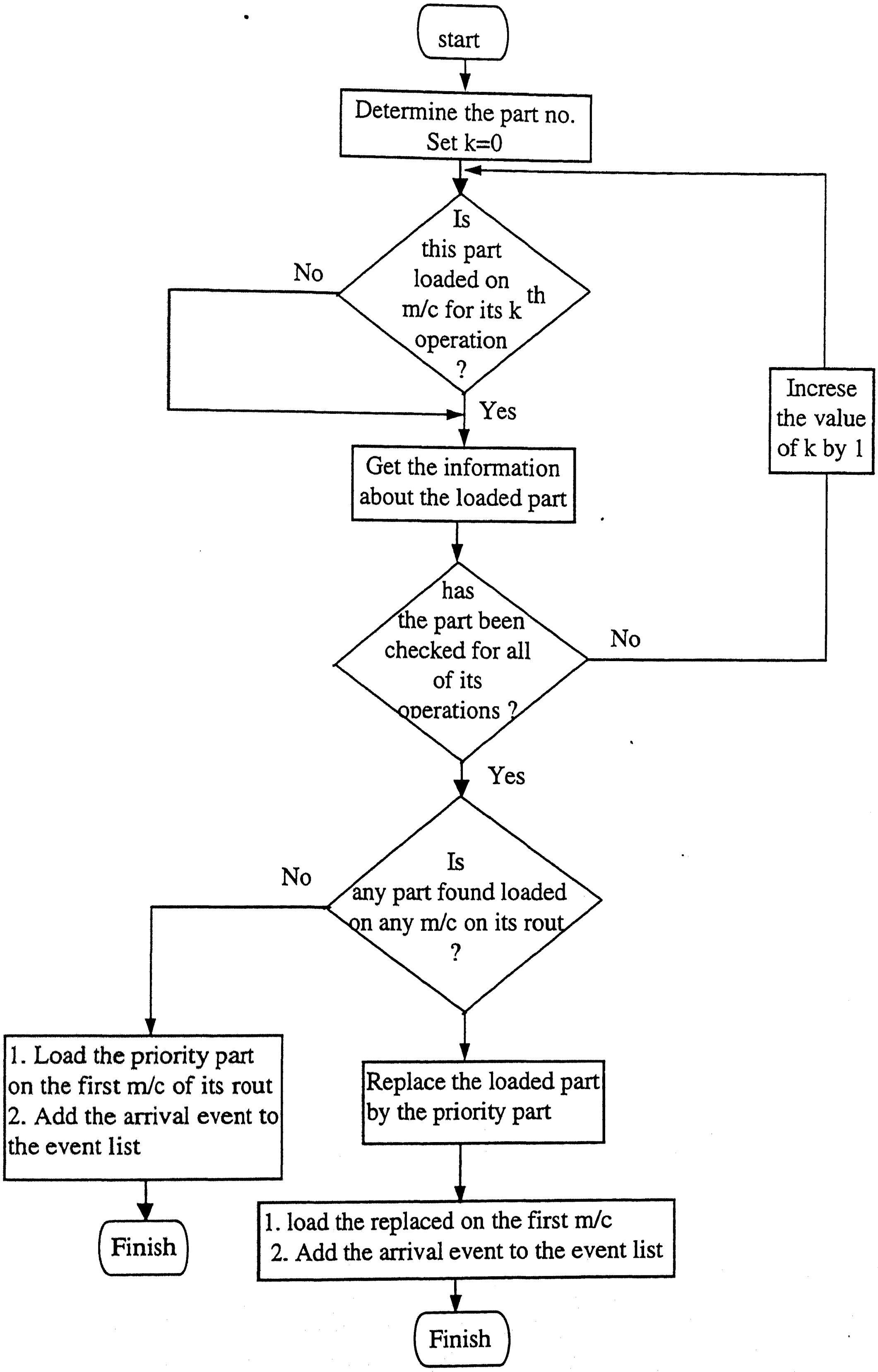

Fig : 3.7 Arrival of an Immediate priority part

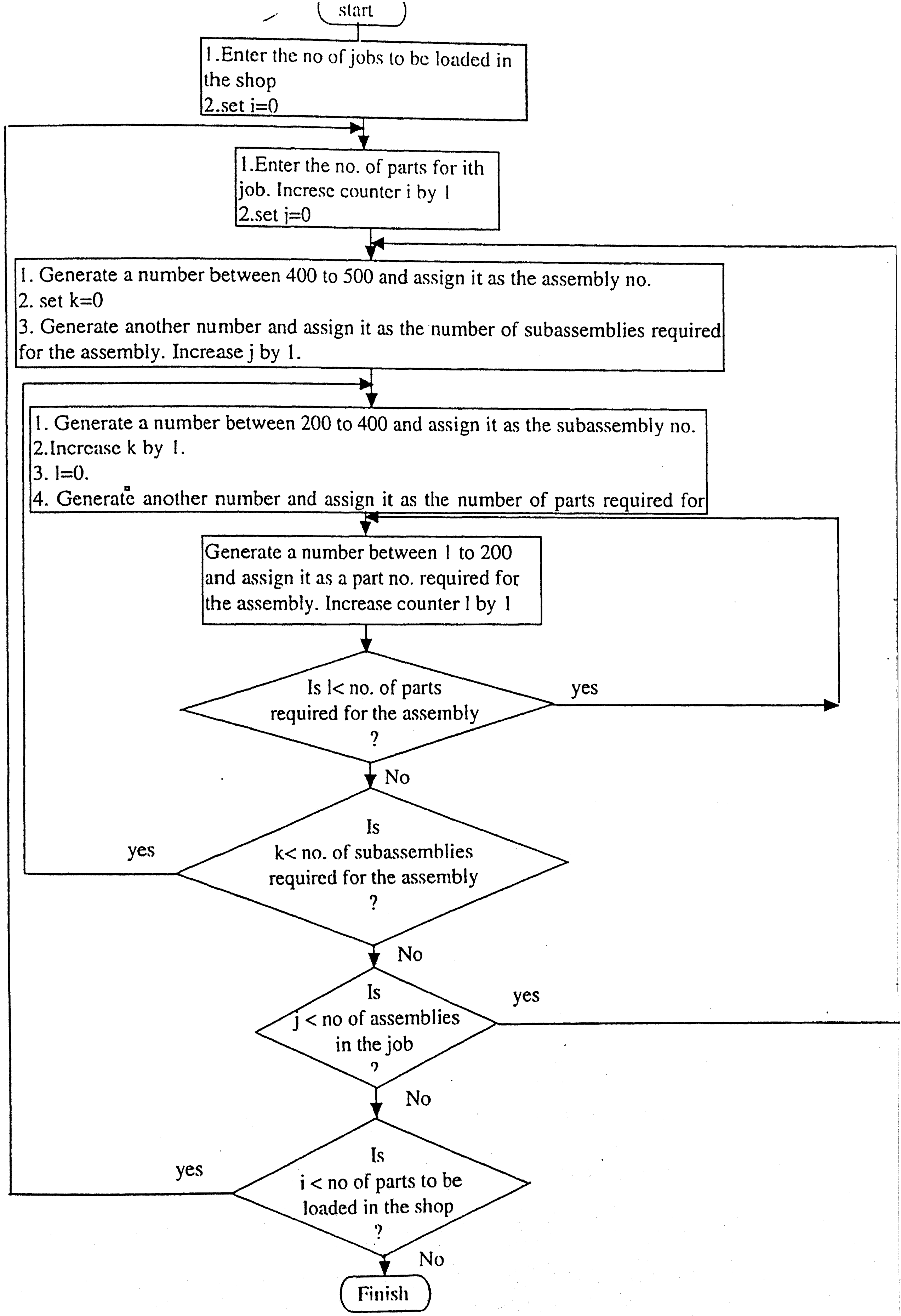

Fig 3.9 : flow chart for requirement file generation

4

PLANT EFFICIENCY AND DISPATCHING RULES

In this chapter we will consider the effect of dispatching rules and plant efficiency on the lead time estimates.

4.1 Effect of Dispatching Rules on Lead Time

As we have described in the chapter 2 that one of the part of the job shop scheduling is the sequencing of the jobs on the machines. So the job sequencing is a critical part of job shop scheduling. Sequencing of the jobs on the machines can be done by using different job dispatching rules. The choice of a particular job dispatching rule depends upon the choice of the measures of performance, taken as the objective of the organisation. Some rules performs better in case of some measures of performance but not in case of others. So the choice of a measure of performance is the driver of the choice of a job dispatching rule. Different organisations may have different objectives such as some organisations compete on the basis the delivery of the products on the stated delivery dates by the customer, while others compete on the basis of the cost of the product. In case of first types of organisations, the measure of performance may be the lateness of the products which may lead the organisation to use the rules that are based on the delivery dates and minimises the lateness of the products,. while in case of other types of organisations the objective may be the flow time of the jobs which may lead the organisation to use the rules that minimises the flow time of the jobs. So we see that different organisations that have

different performance criterion. follow different dispatching rules. Thus the objective of the organisation decides the dispatching rule.

The job dispatching rules assigns the different priorities to the different jobs which are to be processed on different machines. Thus a job dispatching rule affects the waiting time of a job in the shop. Different dispatching rules have different prioritising criteria, thus different dispatching rules will result into different waiting time of the jobs. Thus lead time of a product is dependent upon the job dispatching rule followed by the organisation. To study the variation of the average lead time with job dispatching rule, we run the simulation for two problems each with 2000 parts, and gathered statistic for average lead time. During running the simulation, probabilities of machine break down, labour absenteeism and arrival of immediate priority part are kept zero. The results are shown in table 4.1 and 4.2.

Figures 4.1 shows the performance of various dispatching rules. Fig 4.1 shows the graph between average make span of the shop and the various dispatching rules. Rules SPT, EDD. A/OPN, MOD, OST, OCR, CR+SPT, S/RPT+SPT performed well .The intuitive justification for the SPT rule is that it accelerates the parts having the lesser processing times in the shop. Thus it makes the fewer jobs, waiting in the queue. The rules which are using the slack ratios are seen to perform poorly on this front. The reason behind this may be that these rules give higher priority to those parts that are having longer processing times. So these rules force more job ,waiting in the queue. It is certainly an anti-SPT behaviour. That's why these rules could not perform well if Average make span of the shop is considered as the measuring criterion . Rule A/OPN is observed as the best performed rule because it accelerates the jobs that are having shorter processing times. It is because of the fact that in the various due date models more allowance is given to those

parts which are having longer processing times, so while assigning priorities to the parts by A/OPN rule, the parts having longer processing times are assigned lower priorities.

To take care of the variations caused by various dispatching rules followed by different organisations we decided to introduce a rule efficiency factor. A rule efficiency factor is nothing but the ratio of the average lead time of the shop for a particular rule to the average lead time of the shop for the rule which gives the minimum lead time.

4.1.1 Calculation of Rule Efficiency Factor

As mentioned we have used 12 dispatching rules. To see the relative performance of the rules we run the simulation on two problems and gathered the statistic for average lead time of the shop. The data is shown in the table 4.1& 4.2.

Table 4.1: Rule Efficiency Factor

Sr No.	Rules	Average Lead Times	Rule Efficiency Factor
1	FCFS	1241.686035	1.575652
2	SPT	949.455017	1.204822
3	EDD	831.296021	1.054883
4	MST	883.695984	1.21376
5	SCR	1242.852051	1.577131
6	A/OPN	788.046021	1
7	S/OPN	1170.072021	1.484776
8	MOD	824.630981	1.046425
9	OST	824.630981	1.046425
10	OCR	946.607971	1.201209
11	CR+SPT	876.231995	1.111905
12	S/RPT+SPT	876.231995	1.111905

Table 4.2: Rule Efficiency Factor

Sr No.	Rules	Average Lead Times	Rule Efficiency Factor
1	FCFS	1477.527954	1.726
2	SPT	1085.275024	1.267
3	EDD	1047.474976	1.224
4	MST	1091.670044	1.275
5	SCR	1344.744019	1.570
6	A/OPN	856.007996	1
7	S/OPN	1308.456055	1.528
8	MOD	1106.114014	1.292
9	OST	1106.114014	1.292
10	OCR	1150.432007	1.343
11	CR+SPT	1124.442993	1.313
12	S/RPT+SPT	1124.442993	1.313

4.2 Effect of Environmental Factors

Every production unit , no matter how efficient it is, is subjected to some uncontrollable factors such as machine break downs, labour absenteeism, arrival of an immediate priority part etc.

Machine break downs, labour absences directly affect the processing of the part . These events certainly increase the lead time of the jobs. If an immediate priority part reaches to the shop, then if the same part is already loaded in the shop then this part is shifted to the priority order and the shifted part is to be reloaded in the shop. Irrespective of the job dispatching rule used in the shop, immediate priority part is given priority on each machine,. Thus arrival of an immediate priority part disturbs the sequence of the jobs and in turn affects the waiting time of the various jobs. For this study we tried to incorporate some uncontrollable factors(i.e. machine break down, labour absence and arrival of an immediate priority part).

4.2.1 Effect of Changing The M/C Break-Down Level

Fig 4.2 shows the graphs between average make span of the shop and the dispatching rules under the effect of three different M/c break-down levels .These graphs shows the performance of the various rules with no labour absence, no arrival of immediate priority part.

Fig 4.2 shows the variation in the behaviour of the system as expected, as the break-down levels are increased the average make span of the shop is increased. The best performed rule reported are A/OPN, MOD, OST, OCR. Besides having low values of the make span these rules shows the less variability in the behaviour while switching from one level to another level .Rules CR+SPT & S/RPT+SPT acts as a SPT rule because allowances shrinks as break-down level is increased.

4.2.2 Effect of Changing of Labour Absence Levels

Fig 4.3 shows the graphs between the various measures of performance and the dispatching rules under the effect of three different labour absence. These graphs shows the performance of the various rules when no m/c break-down, no immediate priority part arrival.

Fig 4.3 shows the variation of the rules with respect to average make span of the shop. Rules A/OPN , MOD, OST, OCR are noted to have performed well at this front. It is also seen that not much variability is seen for the most of the rules.

4.2.3 Effect of Changing Probabilities of The Arrival of Immediate Priority Parts

Fig 4.4 shows the graphs between the average make span of the shop and the dispatching rules under the effect of three probabilities of arrival of an immediate priority part. These graphs shows the performance of the various rules labour absence.

We see that these environmental factors considerably affects the average make span of the shop. To take care of the these factors we introduce a shop factor. The shop factor is a measure of the relative performance of the shop under actual environment with respect to the ideal shop environment (i.e. one in which there is no machine break down, no labour absenteeism, no arrival of immediate priority part).

4.2.4 Calculation of the Parameters for the Shop Factor

For calculation purpose four levels of the machine break down, three levels of the labour absenteeism and two level of arrival of immediate priority part are considered. We run two problems to gather the statistics regarding the shop factor. We gathered the statistic for average lead time by running simulation on two problems , each problem with 2000 parts, and using two job dispatching rules for both the problems.

Problem # 1

For FCFS rule

Table 4.3 : Average lead times of the shop for problem #1 with FCFS rule

Average Lead time	Probability of M/c break-downs	Probability of Labour Absenteeism	Probability of Immediate Priority Part
2780.999023	0.000000	0.000000	0.000000
3131.820068	0.200000	0.000000	0.000000
3486.631104	0.400000	0.000000	0.000000
3700.396973	0.600000	0.000000	0.000000
2858.487061	0.000000	0.100000	0.000000
3237.509033	0.200000	0.100000	0.000000
3513.137939	0.400000	0.100000	0.000000
3799.804932	0.600000	0.100000	0.000000
2932.434082	0.000000	0.200000	0.000000
3322.206055	0.200000	0.200000	0.000000
3630.500000	0.400000	0.200000	0.000000
3905.622070	0.600000	0.200000	0.000000
2805.928955	0.000000	0.000000	0.010000
3229.773926	0.200000	0.000000	0.010000
3484.940918	0.400000	0.000000	0.010000
3793.100098	0.600000	0.000000	0.010000
2874.184082	0.000000	0.100000	0.010000
3306.099121	0.200000	0.100000	0.010000
3555.957031	0.400000	0.100000	0.010000
3885.152100	0.600000	0.100000	0.010000
2956.782959	0.000000	0.200000	0.010000
3352.023926	0.200000	0.200000	0.010000
3617.308105	0.400000	0.200000	0.010000
3960.660889	0.600000	0.200000	0.010000

By using these data we run the linear regression analysis model by using the SPSS(Statistical Package for Social Sciences). The results are shown below

R Square .99087

Adjusted R Square .98951

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	3	3188597.12635	1062865.70878
Residual	20	29366.01917	1468.30096

F = 723.87456 Significant $F_{.01}$ = ~~.0000~~ '203

The fitted equation for the lead time is given below.

$$\text{Lead Time} = 2798.878864 + 1601.400472*(X1) + 789.966888*(X2) + 4353.031417*(X3)$$

Shop factor = (Lead Time)/b0.

X1 = Probability of machine break down

X2 = Probability of labour absenteeism

X3 = Probability of an immediate priority part arrival

b0 Constant factor that appears in the fitted equation.

For rule A/OPN

Table 4.4 : Average lead times of the shop for problem #1 with A/OPN rule

Average Lead time	Probability of M/c break-downs	Probability of Labour absenteeism	Probability of Immediate Priority Part
717.976990	0.000000	0.000000	0.000000
907.916016	0.200000	0.000000	0.000000
1099.855957	0.400000	0.000000	0.000000
1196.640991	0.600000	0.000000	0.000000
948.219971	0.200000	0.100000	0.000000
1104.203003	0.400000	0.100000	0.000000
1381.396973	0.600000	0.100000	0.000000
792.497986	0.000000	0.200000	0.000000
1000.080017	0.200000	0.200000	0.000000
1113.661987	0.400000	0.200000	0.000000
1322.852051	0.600000	0.200000	0.000000
773.416016	0.000000	0.000000	0.010000
1009.307007	0.200000	0.000000	0.010000
1123.461060	0.400000	0.000000	0.010000

Average Lead time	Probability of M/c break-downs	Probability of Labour absenteeism	Probability of Immediate Priority Part
1291.801025	0.600000	0.000000	0.010000
844.086975	0.000000	0.100000	0.010000
1070.149048	0.200000	0.100000	0.010000
1149.427979	0.400000	0.100000	0.010000
1448.400024	0.600000	0.100000	0.010000
869.437012	0.000000	0.200000	0.010000
1042.687012	0.200000	0.200000	0.010000
1193.787964	0.400000	0.200000	0.010000
1452.265015	0.600000	0.200000	0.010000

R Square .96645

Adjusted R Square .96115

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	3	939293.24889	313097.74963
Residual	19	32607.05598	1716.16084

F = 182.44080 Significant $F_{.01}$ = ~~.0000~~ .203

The fitted equation is

Lead Time = 716.45 + 901.62*(X1) + 416.81*(X2) + 7706.6*(X3).

Shop factor = (Lead Time)/b0.

Problem # 2

For SCR rule

Table 4.5 : Average lead times of the shop for problem #2 with SCR rule

Average Lead time	Probability of M/c break-downs	Probability of Labour absenteeism	Probability of Immediate Priority Part
1598.363037	0.000000	0.000000	0.000000
1709.293945	0.200000	0.000000	0.000000
1800.139038	0.400000	0.000000	0.000000
1856.550049	0.600000	0.000000	0.000000
1608.921021	0.000000	0.100000	0.000000
1724.423950	0.200000	0.100000	0.000000

Average Lead time	Probability of M/c break-downs	Probability of Labour absenteeism	Probability of Immediate Priority Part
1870.586060	0.400000	0.100000	0.000000
1941.340942	0.600000	0.100000	0.000000
1623.635010	0.000000	0.200000	0.000000
1734.124023	0.200000	0.200000	0.000000
1916.781006	0.400000	0.200000	0.000000
2030.957031	0.600000	0.200000	0.000000
1621.141968	0.000000	0.000000	0.010000
1774.996948	0.200000	0.000000	0.010000
1801.209961	0.400000	0.000000	0.010000
1940.458984	0.600000	0.000000	0.010000
1598.849976	0.000000	0.100000	0.010000
1831.884033	0.200000	0.100000	0.010000
1842.560059	0.400000	0.100000	0.010000
2026.342041	0.600000	0.100000	0.010000
1669.022949	0.000000	0.200000	0.010000
1790.272949	0.200000	0.200000	0.010000
1915.739014	0.400000	0.200000	0.010000
2087.122070	0.600000	0.200000	0.010000

R Square .94382

Adjusted R Square .93540

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	3	454064.29949	151354.76650
Residual	20	27025.88018	1351.29401

F = 112.00728 Significant $F_{.01}$ = ~~.0000~~ .203

The fitted equation is

Lead Time = 1566.235 + 589.21*X1 + 415.93*X2 + 4037.38*X3

Shop factor = (Lead Time)/b0.

For A/OPN rule

Table 4.6 : Average lead times of the shop for problem #2 with A/OPN rule

Lead time	Probability of M/c break-downs	Probability of Labour absenteeism	Probability of Immediate Priority Part
481.467010	0.000000	0.000000	0.000000
511.858002	0.200000	0.000000	0.000000
576.971008	0.400000	0.000000	0.000000
619.362000	0.600000	0.000000	0.000000
482.196014	0.000000	0.10000	0.000000
518.461975	0.200000	0.100000	0.000000
576.812988	0.400000	0.100000	0.000000
623.981018	0.600000	0.100000	0.000000
484.764008	0.000000	0.200000	0.000000
535.132019	0.200000	0.200000	0.000000
565.578979	0.400000	0.200000	0.000000
632.583008	0.600000	0.200000	0.000000
506.574005	0.000000	0.000000	0.010000
522.685974	0.200000	0.000000	0.010000
535.427979	0.400000	0.000000	0.010000
623.252991	0.600000	0.000000	0.010000
507.125000	0.000000	0.100000	0.010000
531.583008	0.200000	0.100000	0.010000
570.341980	0.400000	0.100000	0.010000
679.887024	0.600000	0.100000	0.010000
508.721008	0.000000	0.200000	0.010000
524.885986	0.200000	0.200000	0.010000
578.633972	0.400000	0.200000	0.010000
625.336975	0.600000	0.200000	0.010000

R Square .90738

Adjusted R Square .89349

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	3	64314.58962	21438.19654
Residual	20	6564.67006	328.23350

F = 65.31386 Significant $F_{.01}$ = ~~.0000~~ .203

The fitted equation is

Lead Time = 476.89 + 229.98*X1 + 48.77*X2 + 877.40*X3 .

Shop factor = (Lead Time)/b0.

4.3 Conclusion

For calculating the shop factor we have considered three factors machine break down, labour absence and arrival of immediate priority part. We used a linear regression model for the purpose of calculation of parameters for three different variables. The R^2 values for four different combinations is shown below.

Table 4.6 : Table for R^2 values

Problem No.	Rule	R^2
1	FCFS	.99087
1	A/OPN	.96645
2	SCR	.94382
2	A/OPN	.90738

By seeing the values of R^2 we can say that linear model used for the calculation of shop or plant efficiency is good enough. We thus suggest that an overall measure of plant efficiency can be obtained by running a linear regression on historical lead time data and three factors i.e. machine break down, labour absences and arrival of immediate priority part. A shop factor is reciprocal of the plant efficiency.

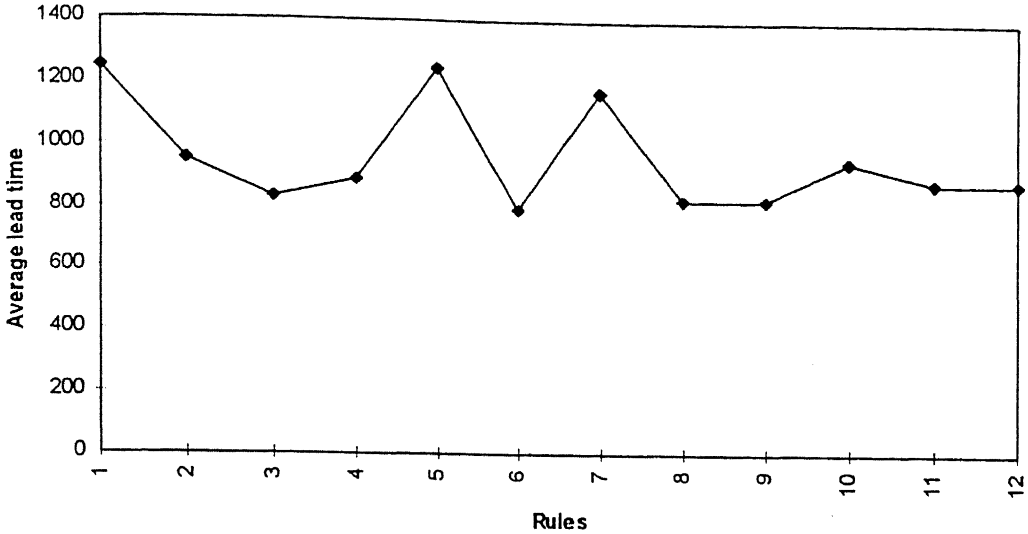

Fig 4.1 Average Lead Time Vs Rules

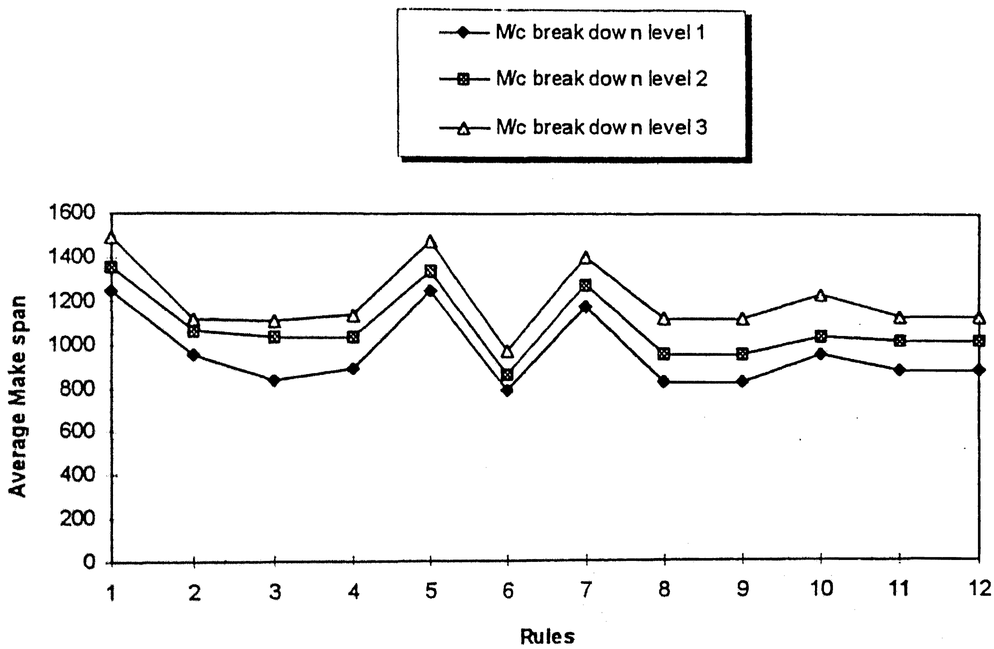

Fig 4.2 Average make span Vs Rules for different m/c break-down levels

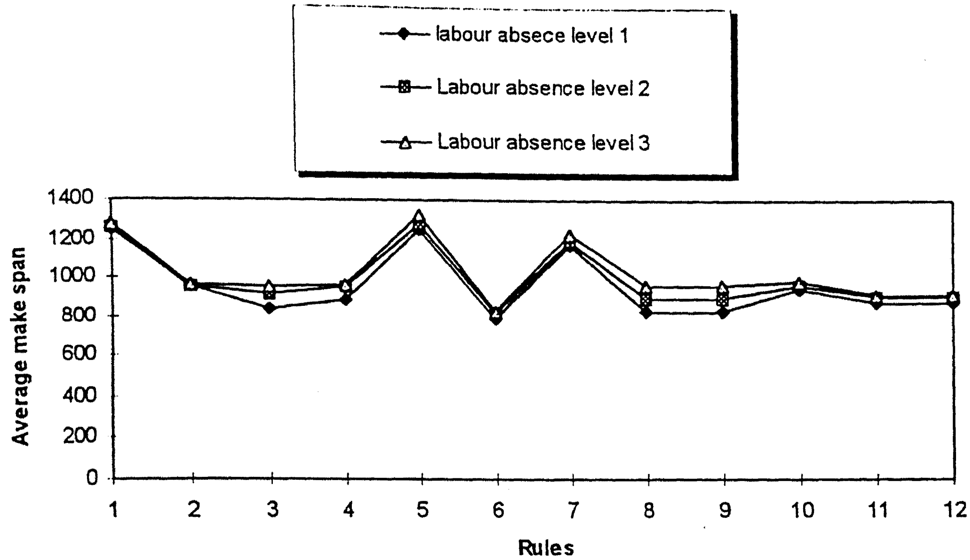

Fig 4.3 Average make span Vs Rules for different labour absence levels

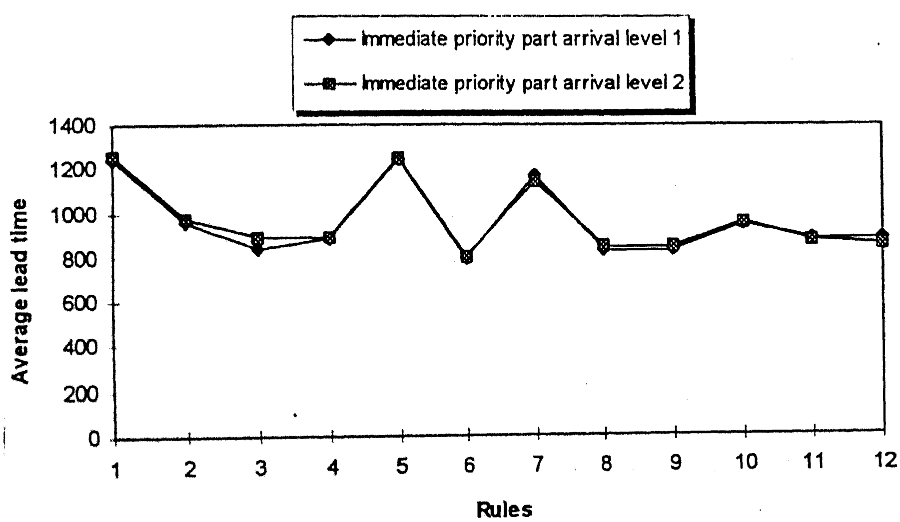

Fig 4.4 Average lead time Vs Rules for differnt levels of an immediate priority part arrival

5

LEAD TIME ESTIMATES

In this chapter we will use the simulation to develop models for lead time estimates. A shop consisting of fifty machining centers ,one inspection center and one transportation center is hypothesised for this study. Loading plan of all the parts is available at the start of the production . No part except immediate priority part arrives during production. Machine break-downs and labour absence problem of a practical job-shop is also taken as the features of the hypothesised shop. Process sheets of all the parts are available. Requirements of the parts and the process sheets of the parts are generated randomly for this study. Problems were generated using the problem generator described in chapter 3.

5.1 Objective of The Study

To develop models to predict the somewhat accurate lead times of the parts in 6 months on 1 year in advance.

5.2 Methodology

If the shop hypothesised for this study would have been a no wait flow shop then the lead times of the parts would have been equal to the total processing time of the job. But it is not a case in a job shop because the parts in the job shop have to wait on the machines for processing. So the lead time of a part in a job shop is defined as the sum of the total

processing time , total waiting time and the transportation time of the job during processing. So the lead time is given as

Lead Time = Total processing time + Waiting time + Transportation time .

As far as the total processing time of the job is concerned it is a deterministic factor because it is a job characteristic . There is no uncertainty involved in this factor. As far as the waiting time is concerned , it is a probabilistic factor (i.e. one can't have the accurate information about the waiting time) because it depends upon the shop loading conditions , capacity of the shop and degree of machine utilization of the shop . There are lot of uncertainties involved in this factor . So in the determination of the actual lead times , main problem is to estimate the waiting time of the jobs. Transportation time is also a probabilistic factor . Due to the probabilistic nature of these factors we can't predict these factors accurately . To have the accurate information about the lead time one will be in the need of the accurate information about the probabilistic factors. But it is not possible in actual practice to have the accurate information about the about these factors. In the literature various factors have been suggested that control the lead time of the part. Some such factors are:

1. The characteristic of work load in the shop (i.e. the routing and the operation processing times of the job).
2. The operating decision rule (job dispatching rule) which controls production scheduling in the shop.
3. The shop structure i.e. the no. of workers and machines present.
4. The shop congestion (i.e. the information about the remaining work of the parts loaded in the shop).

The first factor which requires the information about the no of operations and their processing times is fixed i.e. it will not change with time. The second factor that is the job dispatching rule is an organisations policy to sequence the jobs on the machines which is also not changing during production. The third factor that is shop structure is also fixed unless the organisation is having a dynamic shop structure (i.e. the case in which the management can take can take the strategic decision about increasing or reducing the shop capacity depending upon the shop loading conditions). The fourth factor which is the shop congestion[1] is a time dependent factor.

As the aim of this study is to predict the lead times of the parts 6 months or a year in advance, we can't take the fourth factor for this study because it is impossible to predict about the parts which are to be loaded in the shop after 6 months or a year. To take care of the fourth factor we consider the machine utilization[2].

As mentioned above the lead time of the part depends also upon the job dispatching rule followed by the organisation. To take care of the various dispatching rules followed by different organisations we decided to introduce a rule efficiency factor. A rule efficiency factor is nothing but the ratio of the average lead time of the shop for a particular rule to the average lead time of the shop for the rule which gives the least lead time.

Besides the above described probabilistic factors, there are many unforeseen factors such as machine break down, labour absenteeism, arrival of an immediate priority part (if an immediate priority part reaches to the shop then if the same part is loaded in the shop, then that part is shifted to priority order and the shifted part is to be reloaded in the shop. Immediate priority

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[1] Shop congestion may be defined in terms of average waiting time of the shop , average queue length of the shop ,remaining work of the parts loaded in the shop.

[2] Machine utilization is defined as the ratio of the parts which will see that machine to the total no. of parts

part is given priority on each machine which are to be seen by the part irrespective of the job dispatching rule followed by the shop.).

To take care of these factors we introduced a shop factor. To calculate the shop factor we use linear regression analysis approach. The model used to calculate the shop factor is given below.

Shop Factor = (b0 + b1*(probability of a machine break_down) + b2*(probability of worker to be absent) + b3*(probability of an immediate priority part arrival)) /b0.

The following factors which influence the lead time of a part are considered for this study

1. The total number of operations of the part
2. The total processing time of the part
3. Level of the part (i.e. whether the part is an assembly or not if it is an assembly on which level is it)
4. A rule efficiency factor (To take care of the different job dispatching rules followed by different organisations)
5. A shop factor (To take care of the various unforeseen factors such as machine break-down , Labour absenteeism , arrival of an immediate priority part etc.)

To develop models we need the actual lead times of the parts . In a purely deterministic system , where arrival and processing times are known in advance, not only for the jobs in question , but for all current and future jobs as well, it is possible by simulation to determine precisely (for a given set of rules of priorities and scheduling) when the job will be completed. So a

simulation model which is described in the previous chapter is used for the calculation of the actual lead times of the parts.

After simulating the lead times, regression analysis is used to calculate the coefficients of the various factors used in the lead time model. For linear regression analysis we use stepwise regression[1] analysis.

5.2.1 Models Used For This Study

Three lead time calculation models are used for this study which are described below. To have initial idea about the nature of effect of various factors on the lead times we have fitted the equations to the variation of the lead times with respect to one factor keeping the other factors constant. Fig 5.1 shows the variation of the lead time while changing the no of operations. Fig 5.2 shows the variation of the lead times while changing average utilisation of the machines. Fig 5.3 shows the variation of the lead times while changing level of the parts .

In case of no of operations cubic and exponential equation fits best, so we are using the qubic and log model for this study.

5.2.1.1 Linear Model

Lead Time = b0 + b1*(NOP)^2 + b2*(TWK) + b3*(Average utilization) + b4*A1 + b5*A2 + b6*A3 .

where NOP is the total no of operations.

TWK is the total processing time of the job.

A1, A2, A3 are the factors to represent the level of

---

[1] For details see the appendix A

[2] If part is on the part then the total NOP will be the total no of operations to be done the part but if the part is

If A1=1 job is on part level. the part.

A2=1 job is on sub assembly level.

A3=1 job is on assembly level.

5.2.1.2 Cubic Model

Lead Time = b0 +(b1*NOP + b2*NOP**2 - b3*NOP**3) + (b4* Average utilization + b5* Average utilisation**2 - b6* Average utilisation**3) + b7*A1+ b8*A2 + b9*A3.

5.2.1.3 Log Model

Lead Time = b0 + b1*ln(NOP) + b2*ln(TWK) + b3*(Average utilization) + b4*A1 + b5*A2 + b6*A3 .

The final model will be

Revised model = (Lead time estimation model) * (rule efficiency factor) * (shop efficiency factor).

5.3 System Configuration

The following system configuration including the details about the machines , control variables and environmental factors is considered.

5.3.1 Control Options :

The control options considered here for the experimentation are given below .

5.3.1.1 Dispatching Rule

For the assignment of job operations on the machines the rules used are (1) FCFS , (2) SPT , (3) EDD , (4) MST, (5) SCR , (6) A/OPN , (7) S/OPN, (8) MOD , (9) OST , (10) OCR , (11) CR+SPT, (12) S/RPT+SPT.

5.3.2 Environmental Factors

5.3.2.1 Machine Break Down

The outputs are obtained for three levels of machine break downs. The following three levels are taken for this study.

Level 1 (No break down is occurred during the production).

Level 2 (The probability of the break down is taken 0.2).

Level 3 (The probability of the break down is taken 0.4).

Level 4 (The probability of the break down is taken 0.6).

5.3.2.2 Labour Absence

The outputs are obtained for three levels of labour absence. The following three levels are taken for this study.

Level 1 (No labour is absent during the production).

Level 2 (The probability of a labour to be absent is 0.1).

Level 3 (The probability of a labour to be absent is 0.2).

5.3.2.3 Arrival of An Immediate Priority Part

The outputs are obtained for three levels of arrival of an immediate priority part. The following three levels are taken for this study.

Level 1 (No immediate priority part is arrived during production).

Level 2 (Probability of arriving an immediate priority part is 0.01).

5.4 Initialization

For the comparison of the results of simulations, the methodology most often employed is to simulate the operation of the shop for a specific length of time and to collect the statistics on jobs that are completed. Common statistics of interest are the mean and variance of the flowtime, lateness, tardiness, or weighted measures of the above. Since a number of jobs remain uncompleted at the end of each simulation run , each run really represents a sample from which certain elements do disappear. This is known as the censored data . All other things remaining equal, a job that is running late is less likely to be completed by the time the simulation terminates than the one that is on time. Thus the effect of having a censored date is to create a bias on the lower side of all these estimates. This bias is almost certainly unequal for different dispatching rules.

Conway has devised a way to avoid the censored data problem by numbering the jobs as they enter the system and data of some early job numbers are discarded to reduce the bias due to low shop loading at the starting of the simulation run. In this study the jobs are numbered as suggested by Conway and the first 1000 jobs are discarded and data regarding the next 1000 jobs are collected. Common random numbers are used for comparing different policies.

5.5 Results

5.5.1 Calculation of The Parameters For Lead Time Estimation

For the calculation of the parameters for the lead time estimation model we run the shop in ideal environment (i.e. with no machine break down, no labour absenteeism, no arrival of immediate priority part). We followed the FCFS rule for the calculation of the lead times of the parts because all the other rules (i.e. SPT, EDD, MST, A/OPN etc) depends upon the either on the job characteristic or on the due date assignment methods (in case of rules which depends upon the due dates) which in turns depends upon the job characteristics. In the lead time estimation model we are using these job characteristics. If we would be using any dispatching rule other then the FCFS rule then the sequencing of the parts on the machines will be dependent upon the job characteristics and hence would be affecting the lead time calculation of the parts. We run two problems for the calculation of the parameters.

For problem # 1

For Linear Model :

The fitted equation is

$$\text{Lead time} = 259.77 + 29.76*\text{NOP} + 3.70*\text{TWK} + 130.03*(\text{Average utilization}) - 258.90*\text{A1}.$$

R Square .72550

Adjusted R Square .72440

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Adjusted R Square .72440

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	4	257059683.43861	64264920.85965
Residual	995	97260121.96539	97748.86630

F = 657.44927 Significant F = .0000

For Cubic Model :

The fitted equation is

Lead time = -20419489.91 + (73.157409108 *NOP -.551766857*NOP**2 - .002273479 *NOP**3) + (-1308.037905 *Average utilization + 1204.891424*Average utilisation**2 - 314.25297238*Average utilisation**3) + 20419836.688 *A1 + 20419853.632 *A2 + 20419798.636 *A3 .

Analysis of Variance

Source	DF	Sum of Squares	Mean Square
Regression	10	1803078724.94	180307872.494
Residual	990	93025203.0616	93964.85158
Uncorrected Total	1000	1896103928.00	
(Corrected Total)	999	354319805.404	

R squared = 1 - Residual SS / Corrected SS = .73745

For Log Model :

The fitted equation is

$$\ln(\text{Lead time}) = 4.206383 + .858198*\ln(\text{NOP}) + .057026*\ln(\text{TWK}) + .185877*\ln(\text{Average utilization}) - .039118*A1 - .108539*A3$$

R Square .79741

Adjusted R Square .79639

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	5	364.36104	72.87221
Residual	994	92.56921	.09313

F = 782.49532 Significant F = .0000

For problem # 2

For Linear Model :

The fitted equation is

$$\text{Lead time} = 149.565124 + 34.910296*\text{NOP} + 3.359667*\text{TWK} + 201.215017*(\text{Average utilization}) - 236.223758*A1 + 100.825071*A3$$

R Square .71126

Adjusted R Square .71029

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	5	516285611.39355	103257122.27871
Residual	1494	209589139.03579	140287.24166

F = 736.04072 Significant F = .0000

For Cubic Model :

The fitted equation is

Lead time = -28728584.63 + (70.787350888 *NOP - .400981757 *NOP**2 -.002223167 *NOP**3) + (-2176.699689 *Average utilization + 1889.2590888*Average utilisation**2 - 474.29047914 *Average utilisation**3) 28729286.183*A1 + 28729312.169*A2 + 28729354.437 *A3 .

Source	DF	Sum of Squares	Mean Square
Regression	10	3619696431.51	361969643.151
Residual	1490	206316716.492	138467.59496
Uncorrected Total	1500	3826013148.00	
(Corrected Total)	1499	725874750.429	

R squared = 1 - Residual SS / Corrected SS = .71577

For Log Model :

The fitted equation is

ln(Lead time) = 4.223515 + .852048 *ln(NOP) + .059138 *ln(TWK) + .213328 *ln (Average utilization) + .042733 *A2.

R Square .78825

Adjusted R Square .78768

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	4	490.56557	122.64139
Residual	1495	131.78475	.08815

F = 1391.27541 Significant F = .0000

5.6 Conclusion

For two problems, and three models for each problems the values of R^2 is given in table 5.1.

Table 5.1 : Values of R^2

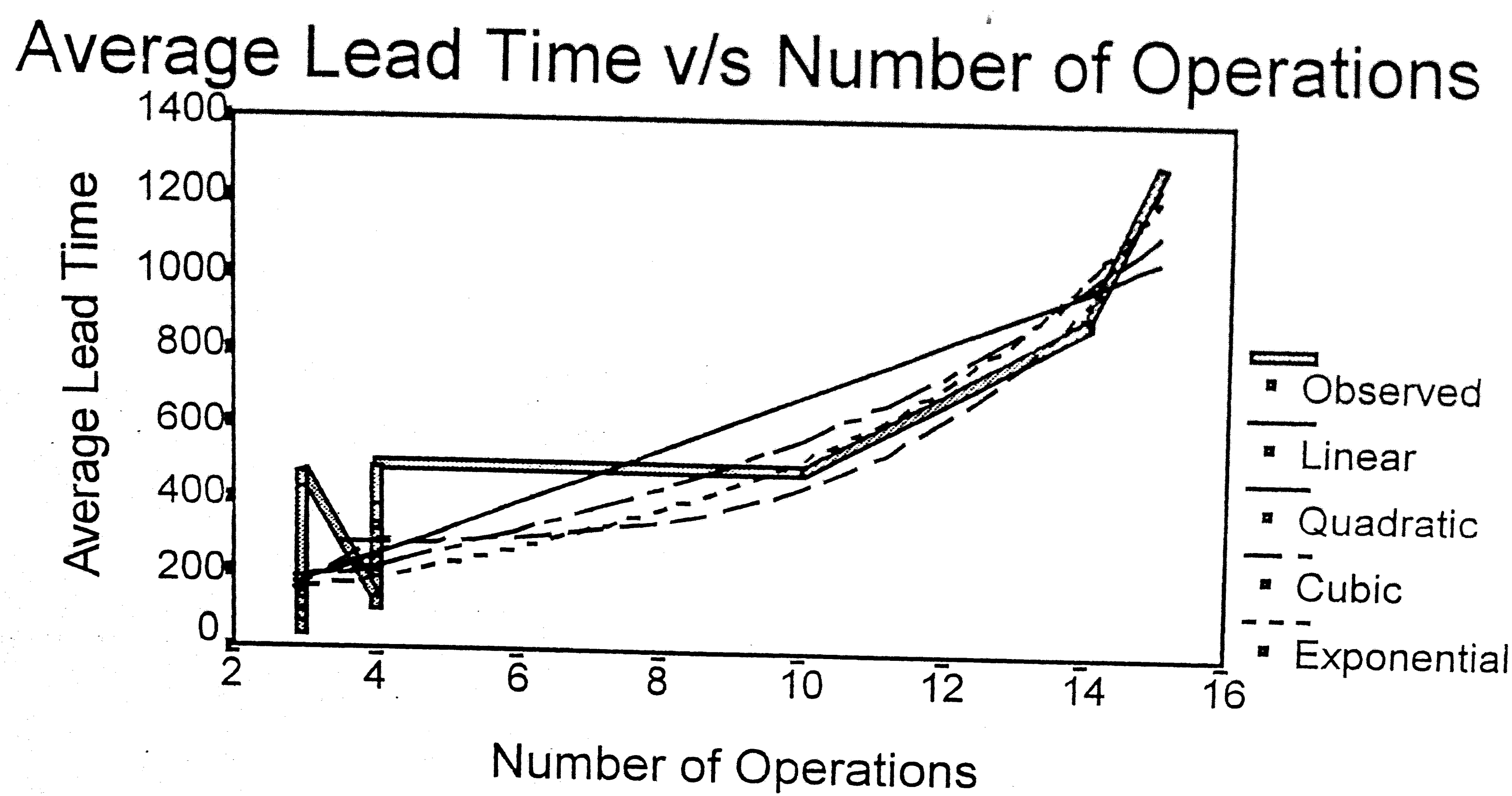
Models	value of R^2	
	Problem # 1	Problem # 2
Linear model	.72550	.71126
Qubic model	.73745	.71577

Models	value of R^2	
Log model	.79741	.78825

From the table we see that log model performed best in both the case. So log model is the best model for calculation of the lead time estimates.

In conclusion we suggest the following methodology for the estimation of the lead time.

1. Establish a plant efficiency factor (shop factor is the reciprocal of the plant efficiency factor) for the shop using linear regression on the following factors.
    - Machine break downs
    - Labour absenteeism
    - Arrival of immediate priority part
2. Establish a dispatching rule efficiency factor
3. Calculate lead time using log model.
4. Calculate actual lead time as the product of plant efficiency factor, dispatching rule efficiency factor, and the lead time estimate for the log model.



Average Lead Time v/s Number of Operations
Average Lead Time
1400
1200
1000
800
600
400
200
0
2
4
6
8
10
12
14
16
Number of Operations
Observed
Linear
Quadratic
Cubic
Exponential

Fig. 5.1

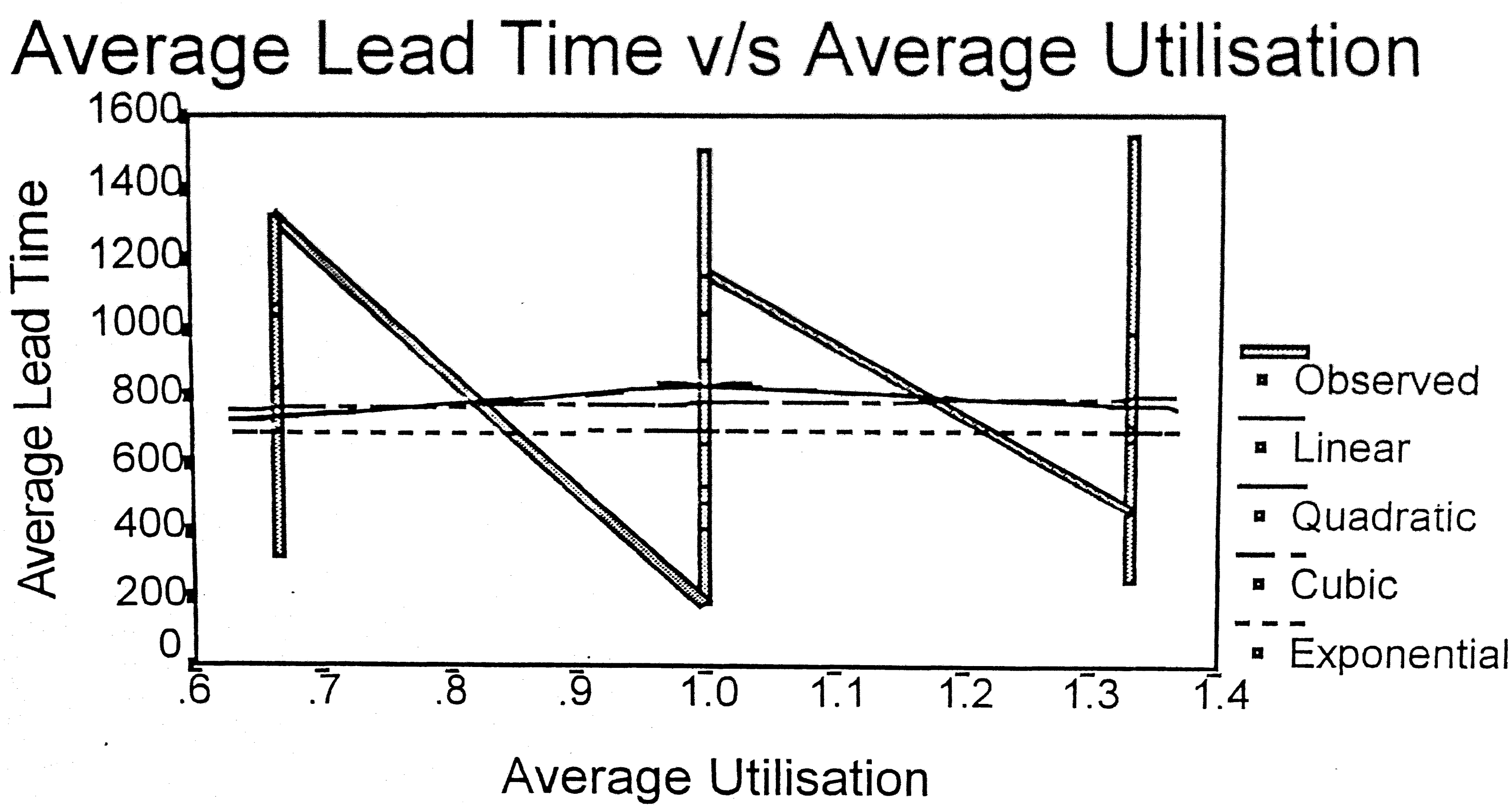
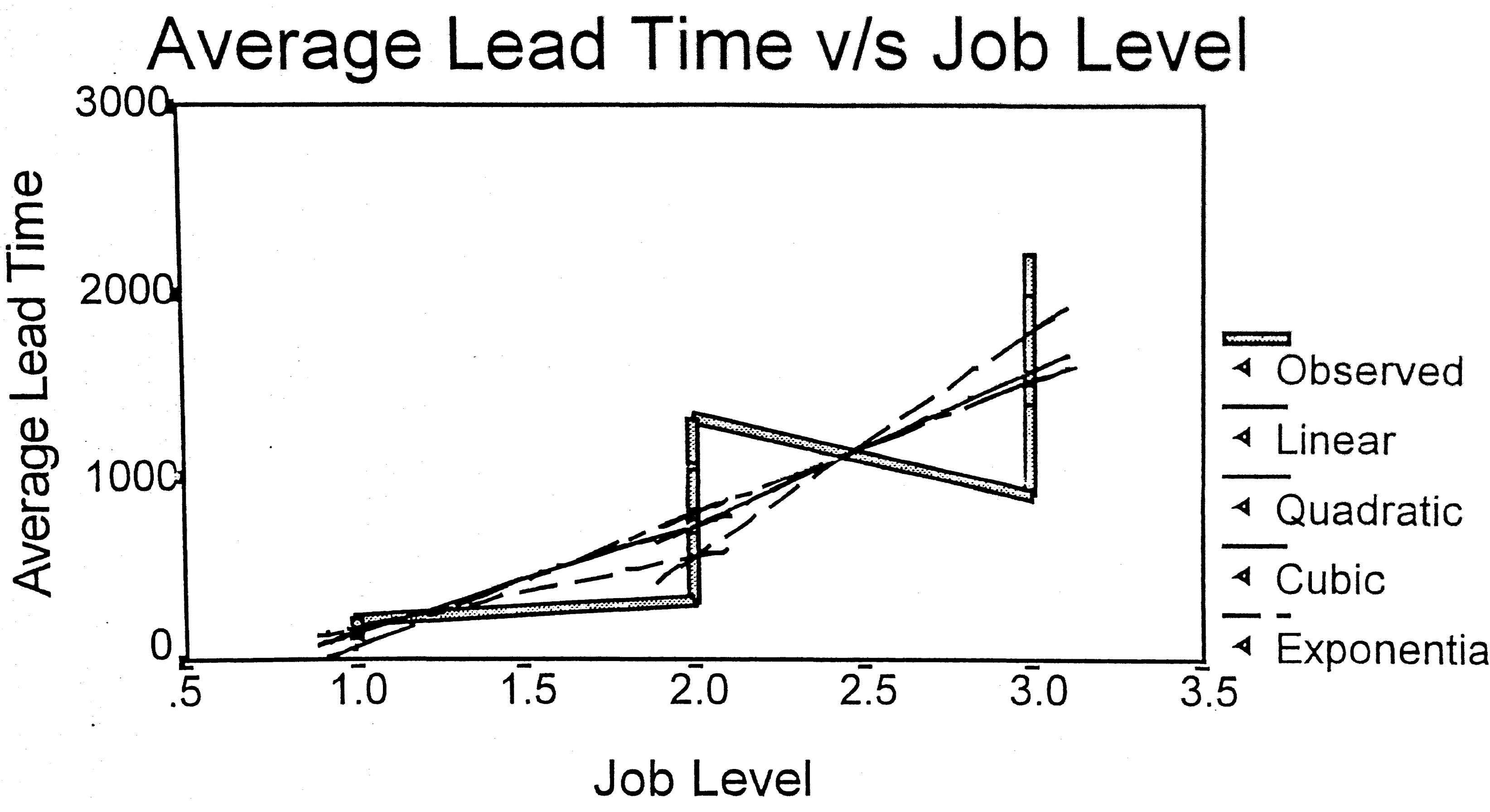

Average Lead Time v/s Average Utilisation
Average Lead Time
1600
1400
1200
1000
800
600
400
200
0
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
Average Utilisation
Observed
Linear
Quadratic
Cubic
Exponential

Fig. 5.2



Average Lead Time v/s Job Level
3000
2000
1000
0
Average Lead Time
.5
1.0
1.5
2.0
2.5
3.0
3.5
Job Level
Observed
Linear
Quadratic
Cubic
Exponentia

Fig. 5.3

CHAPTER 6

CONCLUSION

In a job shop environment due to the diversified nature of work , batching or flow line is impractical. The work must be treated as a series of individual jobs with its peculiar routing among the machines. Loading plan of the jobs is an important part of job shop scheduling. For loading plan we will need the lead times of the parts to be loaded in the shop. There are a lot of uncertainities in the estimation of lead times of the parts because of the variations in the waiting time (or queuing time on the machines) of the parts in the shop.

We have taken the lead time estimation problem as a forcasting problem for this study. To approach this method we have recognized the following factors that affect the lead times of the parts in the shop.

1. Number of operations to be performed on the job
2. Total processing time of the jobs.
3. Level of the job (whether the part is an assembly, sub-assembly or a part).
4. Job dispatching rule to be used in the shop for sequencing the jobs on the machines.
5. Shop factor.

First three factors are the job characteristics that are to be loaded in the shop. Job dispatching rule is an organisations policy to sequence the jobs on the machines. The choice of a job dispatching rule depends upon the choice of measure of performance, taken as the objective of the organisation. The shop factor is related to the capability of the shop to take care of the

listed below.

- Probabilities of machine break downs in the shop.
- Probabilities of labour absenteeism in the shop.
- Probabilities of an immediate priority part arrival in the shop.

It was found that the shop factor is a linear combination of the above stated factors. We can estimate the shop factor by fitting a linear curve to the above factors by using linear regression method. Shop factor can bs represented as

Shop factor =(a0 + a1*X1 + a2*X2 + a3*X3)/a0.

Where X1, X2 and X3 are the probabilities of the machine break downs, Labour absenteeism and arrival of an immediate priority part respectively.

To take care of the variations in the lead due to the various job dispatching rules, we have introduced a rule efficiecy factor. A rule efficiecy factor is basically the ratio of average lead time of the shop for a particular rule to the average lead time of the shop using a rule which gives the minimum average lead time of the shop. Rule A/OPN is reported to give the minimum average lead time while SCR is reported to give th maximum average lead time of the shop.

For Estimation of the lead times we tested three different models. Out of these model we found that log model performs better then linear and cubic modles. A log model is given below

ln(Lead time) = a1*ln(X1) + a2*ln(X2) + a3*ln(X3) + a4*A1 + a5*A2 + a6*A3

where X1 is total no of operations required for the job.

X2 is total processing time of the job

X3 is average machine utilisation

A1, A2, A3 shows the level of the job.

If A3 = 1, job is an assembly .

A2 = 1 job is a sub-assembly.

A1 = 1 job is a part.

Finally the lead time of job can be calculated as the product of lead time estimation(by lead time estimation model), rule efficiency factor and shop factor

Revised Model= (lead time estimation model)*(Rule efficiency factor)*(shop factor).

LIMITATIONS OF THE STUDY

Initially we started this problem on the basis of real life lead time estimation problem in one of the large aircraft manufacturing organisations. However we were unable to validate the model due to variability of the data for the organisation. Further we have assumed that process times, are deterministic, while in actual picture they may vary. Factors like scrap, rework which also have impact on the lead time.

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APPENDIX : A

STEPWISE REGRESSION

This is a technique used for selecting variables for a regression.. In this procedure the variables already in the equation are reevaluated at each stage. Because of intercorrelation, a variable that was important at an earlier stage may not be important at a later one. In stepwise regression, before a variable is added , the variable already in the regression with the lowest partial F value is dropped if this value is less than F_{out}. This procedure is summarized in the flow diagram. Note that F_{in} must be greater than or equal to F_{out} or an infinite loop could result.